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Controlling or Complying? The Opportunities and Challenges of Coordinated Technological Change

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Abstract
In this dissertation, I examine firms' strategic actions and outcomes in multi-firm standards consortia, fast emerging as dominant organizational arrangements for coordinating technological change. Building on strategic networks, the resource-based view and technological change research, I demonstrate how firms' positions in technological (patent-based) and relational (alliance-based) networks affect their choices within and between technical standards organizations. Empirically, I focus on committees in the computer industry that devise peripheral interface standards.

The first essay studies firm-level factors that affect progress towards the coordinated standard. Highlighting how the multiplex nature of inter-organizational relationships affects voting behavior of firms, I find that the influence of network resources is contingent upon the type of inter-organizational tie (technological vs. relational). When these ties are considered jointly, firms possessing superior positions both networks exhibit higher support for its progress as they stand to benefit more from the adoption of the standard.

The second essay examines how divergence in member firms' interests may drive new inter-organizational relationships. Although firms that are peripheral in the technological network are disadvantaged with regard to knowledge relevance in the standard-setting process, I show that they can obtain relational benefits from technologically central firms. To enhance the standard's legitimacy by soliciting wide-ranging participation from firms, central firms may be motivated to forge such alliances.

In the final essay, I explore how firms navigate two competing standards - a voluntary standards committee and a sponsor-backed consortium. I examine and contrast firms' product introduction and patenting decisions on the sponsor-backed standard, arguing that while products accelerate the standard's adoption, patents hinder it. I find that while firms that possess prior technological and relational linkages with the sponsor firms tend to introduce more products but fewer patents, the opposite is observed for firms that are technologically central in the competing voluntary standards committee.

Overall the findings from this dissertation greatly enhance our understanding of firms' strategies in multi-organizational contexts that adjudicate technological change and shape technological evolution.

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OF COORDINATED TECHNOLOGICAL CHANGE

Ramkumar Ranganathan

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CONTROLLING OR COMPLYING? THE OPPORTUNITIES AND CHALLENGES OF COORDINATED TECHNOLOGICAL CHANGE

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ABSTRACT

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Ramkumar Ranganathan

Lori Rosenkopf

In this dissertation, I examine firms' strategic actions and outcomes in multi-firm standards consortia, fast emerging as dominant organizational arrangements for coordinating technological change. Building on strategic networks, the resource-based view and technological change research, I demonstrate how firms' positions in technological (patent-based) and relational (alliance-based) networks affect their choices within and between technical standards organizations. Empirically, I focus on committees in the computer industry that devise peripheral interface standards.

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technological network are disadvantaged with regard to knowledge relevance in the standard-setting process, I show that they can obtain relational benefits from technologically central firms. To enhance the standard's legitimacy by soliciting wide-ranging participation from firms, central firms may be motivated to forge such alliances.

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CHAPTER 1: INTRODUCTION

Background and motivation

A central concern in strategic management and organization theory research has been to understand how firms compete in environments characterized by technological change and innovation (e.g. Tushman and Nelson, 1990; Anderson and Tushman, 1990; Christensen, Suarez and Utterback, 1998). That technological change creates both considerable challenges and opportunities for firms is now well-documented by prior research (Henderson & Clark, 1990; Tushman & Anderson, 1986; Rosenbloom & Christensen, 1994; Christensen & Bower, 1996; Tripsas, 1997; Tripsas & Gavetti, 2000; Cooper & Smith, 1992; Benner and Tushman, 2002; Agarwal and Helfat, 2009). Some scholars have categorized current times as “neo-Schumpeterian” with technological change being continuous rather than marked by structural breaks of creative destruction (e.g. Garud and Kumaraswamy, 1995a).

In these environments, even after a dominant design emerges in an industry following a radical technological change (Abernathy and Utterback, 1978; Anderson and Tushman, 1990), there may be continuous refinement of the architecture or platform that spurs both component and architectural innovations and creates ongoing challenges for firms (Henderson and Clark, 1990; Brown and Eisenhardt, 1997). While market-based *competition* (or de-facto standards) is certainly one way that firms attempt to favorably shape such technological evolution, several kinds of multi-organizational structures that bring together firms with non-overlapping (and often divergent) interests to *coordinate* decisions and mitigate uncertainty have become increasingly common. Multi-firm technical committees that develop technology standards are fast emerging as one such alternative organizational arrangement, where the direction of technological change is debated between large numbers of firm representatives (Dokko, Nigam and Rosenkopf, in press; Farrell and Saloner, 1988). The technology standards specification that emerges out of these discussions becomes a blueprint that, in part, directs the future innovation efforts of the materially affected firms. At the extreme, by virtue of network externalities, standards may even completely dictate the future technological trajectory (Arthur, 1989; Katz and Shapiro, 1986; cf. Dosi, 1982; cf. Rysman and Simcoe, 2008).

The growing importance of such multi-firm standards committees is evident by the resources firms are allocating to them (Farrell and Saloner, 1988) and the impact their standards have had on popular products and technologies (e.g. the 3G, Wi-Fi and USB technologies - all ubiquitous today - have emerged from discussions in standards organizations). However, most academic research on technology standards has tended to either focus solely on market-based standards competition (cf.. Chiao, Lerner and Tirole, 2007) or, adopting a policy viewpoint, has attempted to contrast the quality and timeliness of committee-based decision-making with market-based mechanisms (e.g. Farrell and Saloner, 1988; David and Greenstein, 1990; Chiao, Lerner and Tirole, 2007; Simcoe, 2012). From a firm strategy standpoint, standard-setting committees, and more broadly, multi-organizational bodies still remain a "black box" with several critical unanswered questions. For instance, managerial research has very little to offer on the specific choices made by firms *within* these multi-firm committees - ostensibly there are likely to be tensions or tradeoffs underlying these choices as firms with conflicting interests attempt to eke out a common technological agreement. It is both academically and managerially imperative to understand the characteristics of firms that are able to drive shared decisions to their advantage. Similarly, with the emergence of several standards committees with overlapping memberships and competing interests (e.g. 3G, 4G, CDMA, WiMax, Wi-Fi etc.), beyond basic notions of size and rivalry (Axelrod et al, 1995), we do not understand how firms might navigate this complex landscape or for that matter strategize across these committees in terms of technological and product decisions. This dissertation attempts to fill these gaps by building arguments using an inter-organizational conceptual lens to predict several such critical aspects of firm behavior both within and across standards organizations, and by providing representative empirical evidence to support these claims.

Overview of relevant literature

The majority of studies that discuss technology standards have a rich tradition in economics, particularly the economics of innovation and new technologies. The predominant focus in this line of research has been to understand why technology standards arise, what the consequences of standards are from a policy and societal standpoint, the different institutional mechanisms by which standards are formed and the relative merits and demerits of each of these mechanisms. This research informs us that technology standards generally arise in industries where network externalities (increasing returns to adoption) are significant (e.g. Katz and Shapiro, 1986) and compatibility between different components of a complex technological system is essential to drive user demand (David and Greenstein, 1990; Farrell and Saloner, 1992), that these standards can create "lock-in" effects at the industry level (e.g. Arthur, 1989) and that the technological specifications underlying the standard may be sub-optimal (e.g. David and Greenstein, 1990; Farrell and Saloner, 1985). Further, this research has documented that standards may arise either through direct competition (e.g. Fontana, in press; Cusumano et al, 1992) or through coordination and anticipation by the materially affected firms (Cargill, 1989). While the former are called *de-facto* standards, the latter which emerge out of negotiations and deliberations in multi-firm technical standards committees, are labeled *de-jure* standards. Several papers have compared the efficiency and effectiveness of the market-based, laissez-faire approach to standards emerging from the coordinated approach. These studies have argued that although the committee approach is typically slower than the market-based approach, it results in higher quality technological decisions (e.g. Farrell and Saloner, 1988). Reflecting the growth in formal and informal committee-based standards setting bodies since the mid-1990s, recent studies continuing in this vein have begun to conduct more granular inquiries at the committee and firm level of analysis. For instance, Chiao, Lerner and Tirole (2007) compare provisions and laws across different standards-setting organizations. Rysman and Simcoe (2008) and Lemley and Shapiro (2007) focus at the level of analysis of specific intellectual property disclosures from standards committees in order to understand the technological impact of standards and the additional legal and policy challenges posed by these types of arrangements.

Taken together, the findings from these studies predominantly inform normative debates at the policy level about technology standards. The strategic viewpoint of the single firm and its existing relationships with other firms is largely underexplored.[1] From the considerable body of research in strategy and organization theory, we now know that firms' resources and capabilities are heterogeneous and often idiosyncratically developed by path-dependent experiences and opportunities (e.g. Denrell, Fang and Winter, 2003; Nelson and Winter, 1982; Barney, 1991). When a large number of firms with these heterogeneous capabilities attempt to develop a shared technology standard, it is likely that there will be divergent viewpoints (Simcoe, 2012), with the resolution of these conflicts potentially more beneficial to some firms and more detrimental to others. Thus, when analyzing firms' strategic actions within these committees and outcomes of their participation, it is essential to take into account the specific nature of such divergence and how the process of standards formation and conflict resolution within these committees may differentially enable or advantage some firms and constrain or hinder others.

In this dissertation, I use an inter-organizational theoretical lens to understand such divergences and the resolution of conflict in these multi-organizational settings. My theoretical arguments are primarily anchored in strategic networks theory (Gulati et al, 2000; Zaheer and Bell, 2005). Prior studies using strategic networks have shown that firms' resources arising out of the pattern of their inter-organizational relationships affect both strategic decisions & outcomes. The influence of strategic networks on different

[1] There are two notable exceptions - Leiponen (2008), one of the few studies that adopts the firm as the unit of analysis, shows that participation in multiple industry consortia helps firms contribute to standards specifications. Waguespack and Fleming (2009) focus on startups finding that participation in standards-setting organizations improves the likelihood of a favorable liquidity event.

types strategic decisions - including knowledge sharing within the firm (Tsai, 2002), strategic investments (Sorenson & Stuart, 2001), alliance formation between firms (Gulati, 1995a; Gulati, 1999; Walker et al, 1997; Rosenkopf & Padula, 2008) and acquisition decisions (Yang et al, 2011) - has been established in these studies. Similarly the relationship between a firm's strategic network position and different strategic outcomes - including innovation (Ahuja, 2000), firm survival (Baum et al, 2000), market share (Shipilov, 2006) and firm performance (Zaheer and Bell, 2005) - have also been explored. Intuitively, we would expect the influence of strategic networks on firms' conduct to be especially salient in the standards-setting context, as negotiations to arrive at a consensus standard are conducted at the multi-firm level, where prior inter-organizational linkages are likely to have an important bearing.

Although in reality firms are simultaneously embedded in multiple types of inter-organizational relationships, as Shipilov and Li (in press) point out, "prior studies have assumed away the multiplicity of roles, interests, and relationships between organizations". Departing from this assumption of a single type of inter-organizational linkage (e.g. alliances *or* board interlock ties *or* customer-supplier networks etc.), I emphasize the importance of considering multiplex ties – that firms' network resources arising out of these different relationships may both independently and in combination affect their conduct in the standards organization.

I focus on two relationships between member firms that I argue are salient in determining strategic choices in technical consortia –technological knowledge interdependence relations (also referred to as technological network) and strategic alliance ties (also referred to as relational or alliance network). Several scholars studying technological change and innovation have focused on these two types of relationships as being instrumental linkages that drive both firm performance as well as the overall evolution of technology in an industry (e.g. Henderson and Clark, 1990; Afuah and Bahram, 1995; Stuart and Podolny, 1996; Afuah, 2000; Rosenkopf and Nerkar, 2001; Rosenkopf and Almeida, 2003;Adner and Kapoor, 2010).

For instance, Henderson and Clark (1990) show that when the structure of technological knowledge shifts, firms face challenges in adapting in spite of possessing relevant knowledge about specific technological components within the structure. Afuah (2000), Afuah and Bahram (1995) and Adner & Kapoor (2010) focus on the technological interdependence between various firms in an industry as a key factor in the adaptability of these firms to technological changes. Stuart and Podolny (1996) treat these technological knowledge interconnections as constituting a network landscape that they then use to explain how different groups of firms compete. In this dissertation, I will argue that a firm's position within this structure of technological knowledge determines its ability to shape standards discussions.

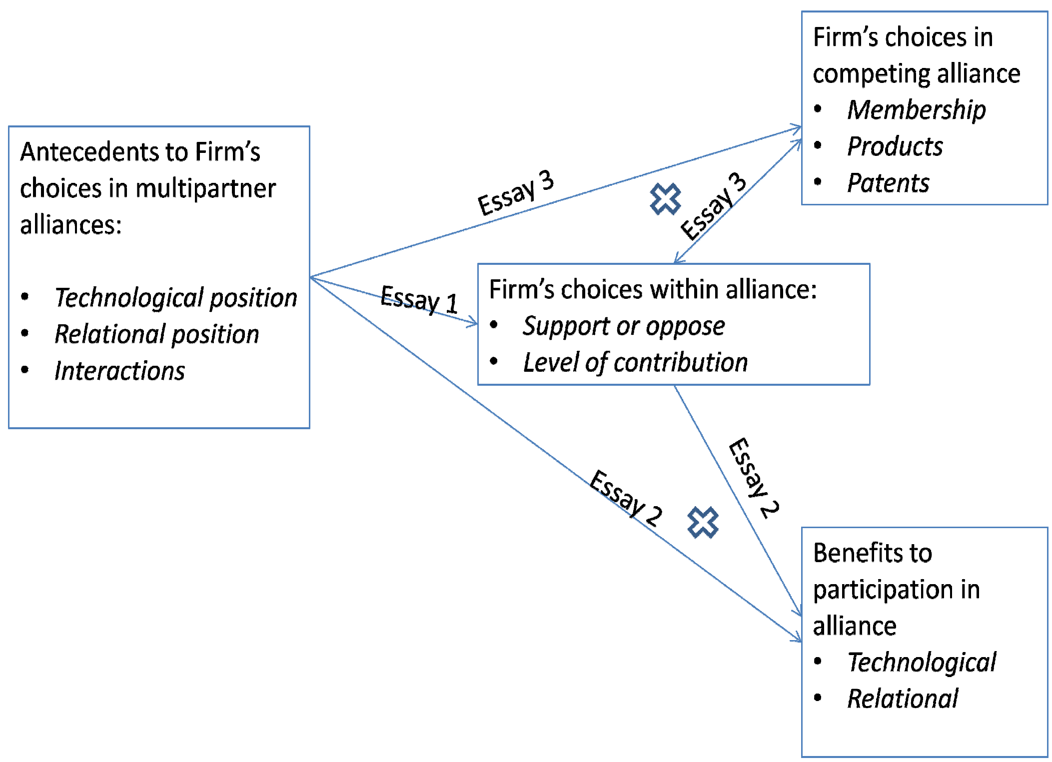
A related stream of research, recognizing that capabilities critical to the firm often reside outside its boundaries (e.g. Cohen and Levinthal, 1990; Rosenkopf and Nerkar; 2001;Dyer and Singh, 1998), has focused on strategic alliances and networks composed of such alliance ties. Alliances are especially critical in dynamic environments, where firms faced with unforeseen technological change may be unable to internally build the capabilities required to adapt to the change (Dierickx and Cool, 1989). That strategic alliances have become ubiquitous is evident by the extent of their adoption across a whole range of industries (Rosenkopf and Schilling, 2007). This stream of research suggests that inter-firm strategic relationships are conduits to accessing new knowledge, building complementary capabilities and distributing innovation challenges across the network of collaborators (e.g. Eisenhardt and Schoonhoven, 1996; Dyer and Singh, 1998; Rosenkopf and Almeida, 2003; Powell et al, 1996; Stuart, 2000; Schilling and Phelps, 2007). In this dissertation, building on this stream of research, I argue that a firm's prior investments in such boundary-spanning relationships will influence both its willingness to support technological standards within a committee and also its actions across multiple standards committees (cf. Christensen and Bower, 1996; Ghemawat, 1991; Taylor and Helfat, 2009). I also theorize on how interactions within the standards committee may further influence formation of such relationships.

Outline of the dissertation

Following this introduction chapter (Chapter 1), I present an overview of the empirical setting (Chapter 2). The core of this dissertation is then organized as three separate essays (Chapters 3, 4 and 5), each of which is focused on a specific research question and the dissertation concludes with an integration of the findings, a discussion of the limitations and directions for future research (Chapter 6).

In the first essay, I ask, what are the antecedents of member firms’ strategic decisions to support or contest standards that are proposed within these technical committees? In the second essay, I study the relational benefits firms derive from participating in these alliances and ask what explains the heterogeneity of these benefits across member firms? Finally, in the third essay, I study competition between different alliance consortia, and in particular I attempt to understand another intriguing aspect of this phenomenon – that many firms actually simultaneously participate in multiple consortia that may have overlapping and even competing interests. Here, I ask - what drives whether and how firms choose to contribute in multiple, competing consortia? The relationship between the three essays is shown in the figure below. Each essay is further elaborated in a separate chapter.

Figure 1: Conceptual links between the dissertation essays.



The following is a brief outline of the arguments in each of these essays.

Essay One: Do Ties Really Bind?

In the first essay, I study firm-level factors that affect efforts to achieve coordination within technical consortia. As technology standards that emerge from these consortia have the potential to erode a firm's competencies (Henderson and Clark, 1990; Baldwin and Clark, 2000; Garud et al, 2002), I propose that a firm's decision to contest these standards is rooted in the divergence of the proposed standards from its technological capabilities and that this divergence can assessed by the firm's position in the network of technological knowledge interdependence relations between member firms of the consortium. Underlying this argument is that principle that the extent to which a firm's technology contributes to the emerging technological trajectory is not only dependent on the properties of this technology but also on the relational context that this technology is positioned within (Podolny and Stuart, 1995).

The technological knowledge network, constructed from patent citation linkages between firms, reveals the technological antecedents of inventions (e.g. Stuart and Podolny, 1996; Stuart, 1998) and thus captures both the structure of knowledge interdependence amongst firms as well as the importance of each firm's knowledge vis-à-vis its consortium peers. I posit that the more centrally positioned a firm is in the network of knowledge relations, the more foundational its knowledge has been in driving prior search and innovation efforts of other member firms, and thus greater the likelihood that the consortium will continue to not only build on these foundational technologies but also resolve conflicts at the core of this knowledge. On the other hand, a firm in a more peripheral position in this network faces the challenging prospect that it will be marginalized in standards discussions, given the tangential nature of its knowledge amongst member firms. Thus, such a firm will be more likely to have a viewpoint that is divergent and more likely to disagree with coordination efforts.

I then contrast this effect of a firm's technological knowledge network position with the effect of a firm's position in a network of prior business relationships (strategic alliance ties) between member firms of the consortium. Although research has emphasized value arising from trust, social capital and relational capabilities in connection with alliance network position (Koka and Prescott, 2002; Gulati, 1995; Uzzi, 1997), I argue that this value is limited in technical consortia where decisions are generally based on technological relevance (Rosenkopf et al, 2001). Instead, firms in central positions in the network of alliance ties are faced with a tradeoff when they participate in technical consortia – they can continue to compete using current technologies without a coordinated standard by exploiting the superior extra-mural complementary assets that derive from their alliance network position (Rothaermel, 2001), or they can risk supporting a new standard that may benefit them (Tripsas, 1997) but that may also erode the value of these assets (Christensen and Bower, 1996; Wu, Wan and Levinthal, 2011). Although complementary assets have traditionally been viewed as helping firms buffer the competence-destroying impact of radical technological change (Tripsas, 1997), the presence of such powerful assets in the form of existing strategic customer and supplier relationships may additionally influence how firms evaluate future technological change (e.g. Christensen and Bower, 1996). Additionally, the more central the firm facing this tradeoff is positioned in the alliance network, the less likely it will meet with retaliation from other firms even it counters coordination efforts to define a common standard (Gnyawali and Madhavan, 2001). Therefore, I argue that the overall tendency for such a central firm will be to slow down the progress of the standard by contesting it within the consortium, thus enabling it to continue or even accelerate the exploitation of its inter-firm complementary asset position outside the consortium.

However, this tendency will be moderated when such firms are also at the center of the technological (knowledge) network –the combination of favorable technological standards with a superior complementary asset position sets up these firms to benefit from the emerging standard, and thus amplifies the necessity to achieve coordination within the consortium.

Essay Two: Give and Take?

Essay Two builds upon the foundational arguments laid out in Essay One. As illustrated in Figure 3, while Essay One argues that the heterogeneity of firms' existing network resources and capabilities is reflected in the heterogeneity of their actions within technical standards consortia, Essay Two suggests that the pattern of interaction, involvement and decisions in the consortia subsequently affects future capability development opportunities of firms. This essay attempts to understand the factors influencing the heterogeneity of such capability development benefits that firms may derive from participating in standards consortia (e.g. Lavie et al, 2007).

I contrast a firm's ability to achieve technological benefits from the standard (e.g. Rysman and Simcoe, 2008) with its ability to achieve strategic alliance benefits (e.g. Rosenkopf et al, 2001). Technological benefits to a firm arise when other firms introduce standard-compliant products and technologies that continue to build on its technological capabilities. Echoing arguments from Essay One, these benefits derive from a firm's position in the technological network of member firms which allow it to ensure that the standard builds on its knowledge base. For similar reasons, these firms may also be more attractive as strategic alliance partners and may even be able to forge these alliances on favorable terms (Stuart, 1998; Stuart, 2000).

However, prior research has suggested that strategic alliances with other member firms may also accrue to a firm because of the level of its involvement and interaction in a consortium (Rosenkopf et al, 2001). By providing these forums for interaction, I argue that technical consortia may open up alliance opportunities especially for firms that are likely to be technologically disadvantaged by the acceptance of the standard. In particular, firms that are becoming increasingly peripheral in the technological knowledge interdependence network of member firms will benefit if they can forge strategic alliances with more central firms in this network (cf. Baum et al, 2000).

However, it is less clear why technologically central firms would form these bridging ties with increasingly peripheral firms. I propose two reasons for this counter-intuitive behavior of central firms and both of these draw upon central firms' incentives to see that a shared standard is coordinated expeditiously so that their technological advantage within the consortium translates into industry-wide technology adoption and performance benefits.

Firstly, central firms need to build the legitimacy of the standard by ensuring that participation in drafting the standard is broad and not confined to those central firms who would obviously benefit from it. As Garud, Jain and Kumaraswamy (2002) illustrate with the example of Sun Microsystems, firms that attempt to push through the standard without wide-ranging support suffer from the ‘sponsor’s legitimacy trap’ which ultimately deters the adoption of the standard. Thus, there is a disincentive for technologically central firms to achieve only the ‘minimum’ coordination to pass a standard. This is also reflected in the informal norms of standards committees where although a two-thirds majority is generally sufficient to proceed with a proposal, outstanding objections and comments are usually given due consideration. Echoing arguments from Essay One, these objections are more likely to come from technologically peripheral firms who perceive the standard to be disadvantageous. The greater the number of objections, the greater the time taken to reach a consensus and the more distant and uncertain the benefits to technologically central firms become. Unresolved objections can lead to even more adverse consequences for the consortium if disadvantaged firms decide to opt out of membership altogether or decide to focus their efforts in a competing standards alliance.

Second, even a small number of modules in the technological system under consideration can lead to high levels of product complexity that mixing and matching different combinations of these modules entails, thus making it difficult for any one firm to control how the technology evolves (Baldwin and Clark, 2000). The example of IBM 360 illustrates IBM's unsuccessful attempt to control the technological evolution of the system although it was the technologically central firm that had foundational knowledge of the system's architecture (Baldwin and Clark, 2000). Thus, there may be a necessity for even technologically central firms to invest in wide-ranging relational capital to counter this uncertainty or possible loss of architectural control. In sum, to enhance the standard's legitimacy and to counter technological uncertainty, technologically central firms may be incentivized to forge bridging alliances with technologically peripheral firms.

Essay Three: Closing the door on open standards?

Essay Three studies orchestration of a competing standards organization by a small number of powerful sponsor firms. I theorize about which firms from the first (non-sponsor backed) standards committee might join the sponsor-backed standard and also what might determine their product development and patenting decisions in this standard. I find that while technological and relational dependence on sponsor firms may drive firms to join the sponsor-backed standard, a firm's technological position in the first committee has an opposing effect. Further, I contrast patenting behavior with products – while technologically central firms in the first standard introduce fewer products that aid in the adoption of the sponsor-backed standard (building on Essay One), they make a higher number of patent claims on it. When firms have prior relational and technological ties to the sponsor firms, opposite effects are observed.

CHAPTER 2: EMPIRICAL OVERVIEW

The International Committee for Information Technology Standards

I focus my empirical inquiry in this dissertation on voluntary standards committees in information technology which, since 1961[2], have been under the purview of the International Committee for Information Technology Standards (INCITS). Accredited by the American National Standards Institute (ANSI), INCITS brings together more than 1700 firms for the creation and maintenance of formal de-jure IT standards. It operates more than 50 different technical committees under ANSI rules which are designed to ensure that voluntary standards are developed by the "consensus of directly and materially affected interests".

INCITS is an appropriate empirical setting to study the emergence of industry-wide information technology standards because it does not have a specific sponsor-backed agenda and allows for equal contribution and representation of all organizations, large and small. It is financially supported by the Information Technology Industry Council (ITI), which is a large trade association representing the majority of the population of firms in the information technology products and services sector[3]. Irrespective of their size, a participating member firm can appoint only one principal voting representative. Further, membership is open to all (including the general public) and the $1200 committee participation fee constitutes a very low entry barrier for firms, thus encouraging the involvement of several small startup firms and independent

[2] Between 1961 and 1997, INCITS was known as the Accredited Standards Committee X3, Information Technology (INCITS website)
[3] ITI members employ more than one million people in the United States and in 2000, their revenues exceeded $668 billion worldwide (INCIS website).

technology consultants. Organizations may also obtain advisory memberships (non-voting memberships) by paying a smaller service fee. Advisory members are allowed to attend meetings, and submit contributions.

INCITS follows several processes to ensure that the standard does reflect a consensus of all the firms involved and is not created out of the vested interest of a few firms. For example, firm representatives vote through letter ballot procedures at several milestones during the standards development process. Both the initiation of a new project as well as the approval of a standards specification requires that a two-thirds majority vote be achieved. More importantly, the INCITS procedures mandate that resolution meetings to address no-votes be held even if the two-thirds majority has been achieved. As documented in the INCITS policies and procedures document, *"the purpose of...letter ballot resolution is to resolve any comments submitted with "No" votes in response to...letter ballots, such that those "No" votes become "Yes" votes and indicate greater consensus...*". Firms are also not permitted from discussing how they are planning to vote on a specific ballot measure. Ballots are generally submitted electronically and results of the ballots are available only after the voting process is complete.

Member firms are also required to voluntarily disclose any proprietary interest they may have in the proposed standards to reduce the risk of antitrust liability. To select standards solely based on technological excellence, the procedures also mandate that firms do not discuss topics such as specific pricing policies, sales plans, customers or suppliers at meetings. Minutes of these meetings are also typically transcribed by INCITS officers and available for public review.

The importance of INCITS as a standards body in the information technology sector is also evident from the more than 750 standards published since its formation. These standards encompass several information technology domains including programming languages, computer graphics, cyber security, distributed processing and computer peripheral interfaces.

Within INCITS, I focus on decision-making within three inter-related sub-committee groups that devise standards for computer peripheral interfaces – namely, the T10, T11 and T13 sub-committees. I track activity in these committees from 1994 (the year T10 was formed) up until 2008. These are interface standards committees in the 'architectural innovation' sense (Henderson and Clark, 1990; Iansiti and Clark; 1994) as the specifications they draft affect different components of a computer system, including the microprocessor circuitry and digital logic to support different peripheral devices (e.g. microprocessors, controller cards and device drivers), the data processing algorithms and protocols to transfer the data between these devices and the computer, the electrical connectors (e.g. USB cables, converter plugs, ports and sockets) that physically transmit this data, and the actual peripheral devices that store or generate this data (e.g. hard disks, digital cameras, portable drives, speakers). The computer industry is also an ideal empirical setting to study the influence of inter-organizational relationships in a technological standards-setting context. This industry is characterized by rapid and sustained technical innovation as well as divided technical leadership amongst firms (Bresnahan and Greenstein, 1999). Although the dominant Windows-Intel ('Wintel') architecture emerged in the 1980s (Hagedoorn et al, 2001), it has undergone significant, and almost continuous change with major component-level innovations (e.g. optical drives and flash memory as opposed to the earlier magnetic tape and disk technologies) and architectural innovations (e.g. the emergence of USB, Firewire and SCSI as different computer peripheral connect standards superseding traditional serial and parallel port interface technologies). Vertically disintegrated platforms have also resulted in the locus of technological innovation being fragmented (Bresnahan and Greenstein, 1999)

The materially affected firms in these committees included companies across the entire value chain of the computer industry. These included semiconductor firms, hard disk manufacturers, cable and controller firms as well as systems software firms. These member firms were also representative of the population of firms in these sectors. For example, in the year 2008 (the last year of the data), INCITS member firms in my sample that were classified under the SIC code 3570 (computers and office equipment) had a combined market share of 95%[4], those that were classified under the SIC code 3571 (electronic computers) had a combined market share of 98% and those classified under the SIC code 3678 (electronic connectors) had a combined market share of 70%. Thus, both complementors (Adner and Kapoor, 2010) as well as competitors (cf. Hagedoorn et al, 2001) co-participated in these committees during the time of study.

The T10 sub-committee is responsible for developing standards for connecting peripheral devices for personal computers, particularly the series of SCSI (Small Computer System Interface) standards including parallel-SCSI and serial-SCSI (Firewire/1394). The T11 sub-committee develops similar peripheral standards, but targets higher-performance computing applications such as connecting multiple devices

[4] Calculated as a percentage of revenues of all publicly listed firms in that SIC code in that year

on a high-speed storage-area network. These standards include Intelligent Peripheral Interface (IPI), High-Performance Parallel Interface (HIPPI) and Fibre Channel (FC). Finally, the T13 sub-committee develops a family of standards called ATA/Serial ATA (AT-Attachment) which is used in connecting a majority of hard-disks today. While all three sub-committees run in parallel, they develop closely related interface standards (the T11 and T13 were created out of the T10 committee).

The Universal Serial Bus Implementers Forum (USB-IF)

In Essay Three where I study the orchestration of a competing sponsor-backed standard, I contrast the Universal Serial Bus standard with the standards emerging from INCITS. The USB standard is a particularly interesting setting to study the evolution of a competing multi-firm standards organization. A sponsor backed consortium, the USB Implementers Forum was also formed in the mid-1990s (around the same time the INCITS voluntary standards committees), thus allowing me to build track records of participation in the voluntary consortium for firms who joined both alliances.

Although both the INCITS and the USB organizations devised specifications to standardize the connection of peripheral devices to computers, they greatly differed in both technical scope and organizational governance. While all firms that join INCITS are part of the standards development projects, the USB-IF was geared towards diffusing the USB technology through promotions, testing and product certification, workshops and developer conferences. Although the USB-IF supported a technical working group to augment and extend the USB standard, the underlying goal was mainly to improve interoperability amongst devices that use the USB standard and not to forge a consensus in the industry around its design. Member fees were also higher when compared to the INCITS committees ($4000 per year). From a development standpoint, there were limited opportunities for non-sponsor firms to modify the base USB standards specification. Whereas INCITS develops non-proprietary standards, the copyright for the USB specification is owned solely by the sponsor firms and not by the standards organization (Source: USB version 2.0 specification). The specification itself clearly categorizes participants in the working group as either "promoter company employees" or "contributor company employees". Although the USB-IF had more than 700 firms listed as members, there were only 13 such contributor companies who participated in drafting the most recent version of the USB specification. This is in contrast to the INCITS standards body where the majority of firms that were members were also active in contributing to the standard.

The first version of the USB specification was put forth by a group of seven sponsor firms, led by Intel Corporation[5] in 1996. This version supported a maximum data transmission rate of only 12 Mega-Bits per second – this was slower by an order of magnitude when compared to some of the INCITS backed standards such as 1394a that supported a transmission rate of more than 400 Mega-Bits per second or Fibre-channel that supported more than 4000 Mega-Bits per second. The transfer speeds on USB were in many instances lower than the peripheral device speeds themselves, thus restricting its use to low performance applications. The objective of the USB standard was to facilitate

[5] This group consisted of Intel, Microsoft, Compaq, Digital, IBM, NEC and Nortel.

an expansion of peripherals, specifically for the Personal Computer (PC), by providing a low cost and easy to configure connectivity solutions without needing to open up the computer chassis to plug the peripheral in (Polishuk, 1998). In contrast with the INCITS standards, the USB technology was designed such that there was a "master-slave" relationship between the host (the microprocessor and controller that were on the PC motherboard) and the peripheral devices (the memory sticks, cameras and other peripheral devices). This meant that the flow of communication, data transfer and even electrical power was controlled from the PC and not from the peripheral devices, thus almost mandating the need for a more powerful microprocessor. It is important to note that although the underlying technological components and modules were the same across these two standards specifications, architecturally, they were very distinct as the sequence and structure of communication between the modules greatly differed.

Although USB was widely perceived to be technologically inferior to the INCITS interface standards, it gained steady acceptance and a large variety of devices supporting the USB standard became available over the years. The USB-IF consortium eventually grew to more than 1000 member firms with more than 7800 certified USB products. About 80 firms from the INCITS voluntary standards consortium also joined the USB consortium.

CHAPTER 3: ESSAY ONE - DO TIES REALLY BIND?

In this essay, I study the firm-level factors that affect progress towards the coordinated INCITS standards, highlighting how the multiplex nature of inter-organizational relationships affects voting behavior of firms in the standards committees.

Introduction

Multi-partner technology standards organizations are fast emerging as the preferred organizational arrangement for coordinating technological change across large numbers of firms. The 3G and Wi-Fi consortia in wireless telecommunications, the Internet Engineering Task Force (IETF) in software and the Firewire and USB standards committees in computer peripherals are well-known examples of such alliances that have had an important bearing on the evolution of technologies and products in these sectors. By developing technology standards, certifying products built on these standards, and providing publicity for these certified products, these alliances have become dominant forums for adjudicating technological change (Rosenkopf et al, 2001; Lavie et al, 2007; Rysman and Simcoe, 2008). Firms too have recognized the importance of participating in these standards-setting alliances – for instance, Intel Corporation, although primarily a chip-maker, actively participates in more than 150 distinct such alliances (source: Intel website). These memberships go beyond silicon and semiconductor standards, to include consumer electronics committees, audio specifications as well as software and web standards.

However, while the focus of prior academic research has been on understanding bilateral inter-firm relationships, less is known about how coordination is achieved within these more expansive multi-lateral organizational arrangements, and what implications such coordination may have on the subsequent fortunes of firms. Two characteristics of such alliances make the question of coordination a particularly interesting and puzzling one. First, as firms that are participating in these alliances each have path-dependent technological capabilities arising from idiosyncratic opportunities and experience (Nelson and Winter, 1982; Patel and Pavitt, 1997; Denrell, Fang and Winter, 2003), the coordinated change is also likely to be a "contested" one, as interests arising from these different capabilities may diverge. Second, the absence of a hierarchical governance mechanism to resolve contests and conflicts between large numbers of firms (which may be possible with alliances involving fewer firms – e.g. Gulati and Singh, 1998) makes the emergence of coordinated change and the popularity of this type of arrangement even more surprising and counter-intuitive. From a managerial perspective, understanding this puzzle is critical to both evaluating investments in such alliances and assessing the subsequent implications of committing to technical decisions emerging from these alliances. In this paper, I take a first step towards illuminating this under-explored, but increasingly important phenomenon by studying firm-level factors that affect alliance-wide efforts to achieve coordination and consensus. I ask, what are the antecedents of member firms' strategic decisions to support or contest standards that are proposed within standards committees?

I focus on both the independent *and* the joint effect of two relationships between member firms participating in a standards committee, on efforts to achieve a coordinated standard– viz. technological knowledge relations (referred to as the technological network) and strategic alliance ties (referred to as relational or alliance network). Using a novel panel dataset of voting records of more than 150 firms over a 14 year standard-setting period in a leading peripheral interconnect standards consortium in the computer industry (INCITS), I find that more centrally positioned firms in the technological network exhibit lower opposition to the standard as their knowledge is more foundational and relevant in developing the standard and resolving conflicts between member firms. In contrast, I find that firms in more central positions in the strategic alliance network are more likely to contest the standard - such positions already endow the firms with advantageous complementary assets that they can continue to exploit without agreeing to the technological change imminent with a shared standard. Thus, the influence of network centrality on firms' actions in a multi-firm setting differs depending upon which type of inter-organizational tie is considered. Moreover, when the multiplicative effect of these relationships is factored in, centrality in the technological network moderates the opposing effect of centrality in the alliance network on consensus formation – firms that possess superior resources in both networks stand to benefit more from a shared standard, and thus exhibit a higher support for its coordination. Thus, consensus may be facilitated by the fact that firms in technologically intensive industries have a history of not only path-dependent capability development but also one of building on extra-mural sources of knowledge (e.g. Rosenkopf and Nerkar, 2001). The ability of a multi-firm technology standards organization to jointly develop a standard may be affected by both the level of knowledge integration of its member firms and the level of symmetry in their strategic alliance collaborations with one another.

This work contributes to research at the intersection of strategy, organization theory and technological change. The findings suggest that the role strategic network resources play in influencing firms' strategic decisions is, in part, driven by both the *context* in which these decisions are being made as well as the *multiplicity* of inter-organizational relationships. The particular contextual emphasis of this paper is on multi-firm standards organizations, an increasingly preferred form for coordinating technological change. This paper also contributes to the literature on technological change and the evolution of technological trajectories. While a majority of studies in the technological change literature emphasize the importance of dominant design and the challenges that firms face in adapting to such discontinuities (e.g. Tushman and Anderson, 1986; Henderson and Clark, 1990), this paper highlights the strategic choices that firms need to make in a post-dominant design era of technological change.

The findings of this study are also managerially relevant. Firms not only need to make decisions whether to support standards, but also need to evaluate the investments they need to make in sending engineers to participate in drafting and contributing to these standards. This is becoming more critical given the proliferation of standards forums in technology-driven industries and their strategic importance. Understanding decision-making in these consortia may also provide insights for policy makers who are interested in determining whether these coordinated outcomes promote industry-wide decisions that benefit consumers or whether they support only a few advantaged firms.

Technology consortia – forums of contested coordination

Shaped by heterogeneous, path-dependent capabilities and beliefs, firms make different strategic bets on technologies (Nelson and Winter, 1982; Denrell, Fang and Winter, 2003). The presence of network externalities and switching costs in technology-driven industries such as personal computers (Katz and Shapiro, 1986) provides a selection mechanism for a 'winning' or dominant design amongst these technologies (Tushman and Anderson, 1986; Schilling, 2002). Although the emergence of a dominant design selects between different technological platforms (Baldwin and Woodard, in press), it leaves considerable scope for future technical elaboration, both at the component and at the inter-component level. Subsequent technological change is often 'de-jure' - where multiple firms cooperatively refine the scope of various components that constitute the system and define standardized rules for how these components should interoperate. The ability of a firm to control the subsequent evolution of these technological trajectories in ways that sustain or enhance the value of its capabilities therefore becomes a crucial determinant of future advantage (Teece, 2007). Technology standards consortia are venues where firms have opportunities to shape such change (Dokko, Nigam and Rosenkopf, in-press). These multi-partner organizations develop voluntary technology standards by the consensus of various firms that are materially affected by these technologies. By shaping choices made within multi-firm consortia, firms can build attributes of their firm-specific technologies into the evolving industry standard (Garud et al, 2002).

Although such expansive multi-firm committees operate to reduce technological uncertainty and avoid costly standards wars (cf. Rysman and Simcoe, 2008), the reality of different firms' private and divergent interests (Garud et al, 2002) is likely to complicate whether an individual firm views these standards as beneficial or detrimental. Decisions made within these committees have significant and divergent consequences for the value of firms' technological capabilities (Rysman and Simcoe, 2008; Dokko and Rosenkopf, 2010). In particular, architectural standards that propose standardized rules for interaction between components or modules (e.g. Henderson and Clark, 1990), have the potential to cause adverse technological, economic and organizational consequences for firms. From a technological standpoint, by forging a consensus amongst different firms about how different components of a technical system interact, standards reduce uncertainty. Products become more modular as technological and market uncertainty reduces (Sanchez and Mahoney, 1996) and increasing modularity results in de-coupling of tasks and functions (Baldwin and Clark, 2000). By uncoupling tasks that are integrated within components and allowing for further component specialization (Schilling, 2000), standards may thus result in architectural competence-destroying technological shifts for firms (Henderson and Clark, 1990). Standards also allow different components to be produced separately and different variants of the same component to be used interchangeably (Garud and Kumaraswamy, 1995a) – again, entailing architectural shifts that may be challenging for firms. From an economic standpoint, conceding to a standard may require rework or retrofit of a firm's technologies to follow the new rules of inter-component interaction specified by the standard. These concessions may also require additional investments in personnel and technological capabilities without an assured economic return in sight. From an organizational standpoint, the effects of cognitive and organizational inertia have been elaborated in research on the challenges of technological change (e.g. Henderson & Clark, 1990; Tripsas and Gavetti, 2000). The changes that the firm needs to make in processes, structure and resource allocations to conform to the new technological order may face opposition within the organization. Status-quo in the existing pattern of commitments to internal and external relationships may be a form of organizational truce (Nelson and Winter, 1982; Christensen and Bower, 1996). In sum, firms may have technological, economic and organizational incentives to not support the emergence of a coordinated standard and may choose to contest the standard if they perceive it to be unfavorable.

As decision-making in voluntary standards committees is consensus based, even contestation by a small number of firms is likely to delay the standard-setting process if not derail it completely. Simcoe (2012) for instance finds that the conflicts arising out of private firm interests led to a delay of more than eight months in the standards process for the Internet Engineering Task Force (IETF) committee. Even if a consensus standard eventually does get published and accepted, such delays may allow an inertial firm to adapt to the new technological rules proposed by the standard. In dynamic settings marked by frequent technological changes, the ability to negotiate and extend the life cycle of products or technologies even by a few months may therefore be critical to a firm’s competitiveness and even survival.

Theoretical arguments

I propose that firms' decisions to contest or support the standard are shaped independently and jointly by their positions in two different networks - the technological knowledge network *and* the strategic alliance network of member firms. Below, I discuss why each of these network positions is pertinent in decision making in the technology standards context and hypothesize on the nature of that influence.

Technological knowledge network position

The technological knowledge network is a structural representation that captures the pattern of how firms have utilized each other's technological knowledge in building their own innovations. If this network is constructed for firms that participate in a technical standards committee, then a particular firm's position in this network may help identify whether the proposed standard aligns with or diverges from the firm's technological capabilities. Essentially, this position is a reflection of the degree to which a firm's knowledge across the different technologies (that constitute the system under discussion in the technical standards committee), is considered central within the committee. Centrality of knowledge then reflects the extent to which the community of firms considers the particular firm's stock of relevant knowledge valuable for drafting the standard.

Such a knowledge network can be constructed by plotting the linkages between firms based on their patent citation patterns for the relevant technology set. Knowledge interconnections are revealed in patent citations which document the technological antecedents of inventions (e.g. Benner and Tushman, 2002; cf. Benner and Waldfogel, 2007)[6]. Citations received by a patent are an indication of that technology's importance, impact and potentially economic value (Hall, Jaffe and Trajtenberg, 2005). This technological structure of markets approach was first introduced in Podolny and Stuart (1995) and further elaborated in Stuart and Podolny (1996) and Stuart (1998). The principle of this approach is that the extent to which a firm's technology contributes to the emerging technological trajectory is not only dependent on the properties of this technology but also on the relational context that this technology is positioned within (Podolny and Stuart, 1995).

Firms that are more central within the technological network will have greater incentives to support the standard. Centrality indicates how foundational the firm's technologies have been in the past, in driving innovation (search) efforts of the other member firms (cf. Stuart and Podolny, 1996). There is thus a greater likelihood that the compatibility rules that emerge from the standards committee will continue to build on these foundational technologies – more specifically, following a local search logic, firms negotiating the standard are unlikely to find a compatibility solution in an area that is distant from the core of the knowledge network (Ahuja and Lampert, 2001; Fleming and Sorenson; 2004; Levinthal, 1997), especially when there are conflicts and contests between firms with divergent technological capabilities. It follows then that firms that are the most centrally positioned are likely to be the closest in terms of 'technological

[6] Patent linkages give a more accurate conceptualization of technological interconnections than product linkages. This is because a firm's technological reach is much greater than its product reach (Patel and Pavitt, 1997) as firms tend to know more than they make (Brusoni et al, 2001).

distance' from the emerging consensus and therefore stand to benefit the most from the standard.

Peripheral firms on the other hand face the challenging prospect that their knowledge will be marginalized in compatibility discussions, given its tangential nature within the community of member firms. Thus the technological change proposed by the consensus standard is more likely to favor firms in central technological positions and less likely to favor firms in more peripheral technological positions. Peripheral firms will therefore be more likely to have viewpoints that are divergent and thus more likely to disagree with the standard. This idea is also consistent with prior research on institutional change that suggests that challenges to any prevailing order are more likely to originate from the periphery of a field than the core (e.g. Kraatz and Moore, 2002). Such firms also have to consider the organizational costs of acceding to an unfavorable standard that requires several stakeholders to overturn their technological assumptions and reconfigure well-established routines (Nelson and Winter, 1982; Burgelman, 1983; Burgelman, 1994). Therefore,

Hypothesis 1: The more (less) central a focal firm is within the technological knowledge network of participating member firms, the lower (higher) its rate of opposition to the coordinated standard.

Strategic alliance network position

A large body of research in strategic alliances and alliance networks has theorized about the advantages that accrue to firms that are central in a strategic alliance network. Firms that are embedded in such a network are posited to possess wide-ranging social capital, relational capabilities and inter-firm trust (e.g. Koka and Prescott, 2002; Dyer and Singh, 1998; Gulati and Singh, 1998), that could be construed as sources of advantage in multi-firm settings. However, although a central firm's influence derived from its accumulated social capital may be valuable, this value is limited in a technical committee that sets standards, particularly where a firm can neither be a focal sponsor of the standard nor control the membership or define the technical agenda. As engineers constitute the majority of participants, formal criteria for evaluating proposals are primarily based on technical knowledge and technical excellence (Rosenkopf et al, 2001). Although the consequences of the standard are strategic to firms, the process itself has a "bottom-up" flavor to it (cf. Rosenkopf et al, 2001). Tactics of politics and influence, including lobbying or attempting to convince other firms' engineers outside the confines of formal meetings may backfire. Technical standards committees also generally limit firms to a single organizational vote, irrespective of the extent of their market power, their inter-organizational influence or the number of engineers they designate to attend committee meetings. Thus, a firm's strategic alliance network position may not readily translate into advantageous technical committee decisions.

Instead, firms in central positions in the network of alliance ties are faced with a tradeoff – they could continue to compete using current technologies without supporting a coordinated standard by exploiting the superior complementary capabilities that derive from their alliance network position (cf. Rothaermel, 2001), or they could opt to support the new standard that may benefit the entire industry but that might also erode the value of these assets (Wu, Wan and Levinthal, 2011). Reflected by their alliance network positions, such firms typically have access to superior complementary capabilities, including an established value chain of suppliers and distributors, well-developed inter-firm electronic exchange systems, and potentially higher order capabilities such as alliance management (Kale, Dyer and Singh; 2002). Prior research that has studied the challenges of technological change for firms has highlighted the critical role such complementary capabilities play in helping the firm capture value during technological change (Teece, 1986) or even buffer the firm from the disruption and erosion of its technological competencies (Tripsas, 1997). However, recent studies extend these arguments by suggesting that complementary capabilities may also be a 'prism' through which firms evaluate technological options (Wu, Wan and Levinthal, 2011). If technology standards are adopted, then the transition to these standards may completely devalue the usefulness of these complementary capabilities for firms (Taylor and Helfat, 2009) and such considerations will affect how firms view the option to support or contest technological standards. If a firm's inter-firm complementary capabilities are powerful but are also specific to the existing technological order or architecture of the system, then it is more likely to view the standard as a capability-eroding shift and contest it. Even when a firm possesses more flexible complementary capabilities that may be potentially re-deployable under different technological orders, the uncertain nature of technological change spurred by the standard may cause such a firm to resist it. The example of IBM's

360 illustrates how a firm may adopt a conscious strategy of controlling the architecture of a system, but may still fail to achieve this control (Baldwin and Clark, 2000). The modular nature of modern technological systems leads to high levels of product complexity that mixing and matching different combinations of these modules entails, thus making it difficult to predict how the technology co-evolves with the diffusion of different module combinations (Baldwin and Clark, 2000). By slowing the standard's emergence, such a firm will at the very least be able to gradually phase in the necessary capability adjustments in order to transition over to the new standard.

The example of the personal computer industry illustrates the challenges standards pose to firms' complementary capabilities by devaluing their alliance network positions. In the early 1990s, increasing standardization within and between computer components led to increasing modularity and de-integration of the supply chain, enabling the entry of several component manufacturers ("OEM"), resellers ("VARs") and other distributors. Such fine-grained specialization and standardization in computer modules allowed startups such as Dell Computer to design just-in time fulfillment and delivery systems by bypassing the traditional supply chain. This de-valued established PC manufacturers' (e.g. IBM, Digital, HP, Compaq) investments in their alliance networks. Eventually, this led to the merger of Digital, HP and Compaq and the sale of the PC business by IBM.

Even when firms do recognize the need to build organizational linkages between an emerging technological standard and existing complementary capabilities to sustain the value of these capabilities (Taylor and Helfat, 2009), existing commitments to downstream customers and upstream suppliers may restrict their ability to carry out such changes (e.g. Christensen and Bower, 1996). These constraints will be more pervasive for firms that are more centrally embedded in the alliance network (Uzzi, 1997). Thus, such firms are more likely support the existing technology order rather than risk obsolescence of their complementary capabilities from new technological standards. By contesting the standard, such firms at the very least may buy additional time that can then be used to make the necessary technology investments as well as the internal and external organizational reconfiguration to support these investments while simultaneously exploiting their current alliance position to the maximum.

Additionally, firms that are in central positions in the alliance network derive greater bargaining power from these positions as they control resource flow within the network, including information about the nature of technological investments of partner firms, their product quality as well as their fidelity. By virtue of such control, these firms can afford to undertake more self-serving actions in multi-firm settings, such as contesting attempts to coordinate a shared outcome. The likelihood that such actions will be met with retaliation diminishes with the asymmetry between such central firms and the rest of the network (Gnyawali and Madhavan, 2001; Chen, 1996). Therefore,

Hypothesis 2: The more (less) central a focal firm is within the strategic alliance network of participating member firms, the higher (lower) its rate of opposition to the coordinated standard.

The multiplex effect – joint influence of the two network positions

Although firms that are centrally positioned in the strategic alliance network will have a greater tendency to contest the standard, this tendency will be moderated when such firms are also at the center of the technological network. The combination of favorable technological standards with superior inter-firm complementary capabilities sets up these firms to benefit the most from the standard, and thus makes it even more imperative for such firms to achieve coordination. A more central technological position will dampen the incentives for such firms to oppose the standard as technological divergence is reduced. The more the other consortium member firms consider the firm's knowledge foundational, the more the standard's rules are likely to favor it. The combination of technological influence as well as better inter-firm capabilities from a stronger alliance position suggest that such a firm is well-positioned to favorably shape the standard within the committee and also expeditiously build and license technology outside of it. Further, such a firm's extensive prior extra-mural commitments reveals the presence of boundary-spanning knowledge conduits and a more flexible, modular organizational structure (Schilling, 2000) that resolves issues of local search and organizational inertia (Rosenkopf and Almeida, 2003) which might otherwise impede the firm's support for the standard. Therefore:

Hypothesis 3: The more central a focal firm's technological network position, the lower the positive effect of its strategic alliance network position on its rate of opposition to the coordinated standard.

Figure 1 summarizes these arguments. The horizontal axis represents a firm’s position in the network of inter-firm technological knowledge, while the vertical axis is its position in the network of inter-firm strategic alliance relationships. Firms located in the right side of the matrix, i.e. in quadrants 2 and 4, are the technologically central firms that are more likely to be advantageously positioned with respect to the technology proposed by the standard, whereas firms located in the left hand side of the matrix - in quadrants 1 and 3 - are the technologically peripheral firms that are more likely to have divergent technological viewpoints not incorporated in the standard. Similarly, firms located in the top half of the matrix, quadrants 1 and 2 are more likely to have strong inter-firm complementary capabilities that negatively influence their support for any technological change through the standard whereas firms located in the bottom half of the matrix in quadrants 3 and 4 have weak inter-firm complementary capabilities that make them less predisposed against the coordinated standard. The interesting interaction between these two network positions is captured in the upper right hand quadrant 2 – as firms with strong complementary capabilities are also in favorable positions to benefit technologically from the standard, they are likely to increase support for achieving a coordinated standard.

Figure 2. Summary of arguments for Essay One

Firm's Position in Strategic Alliance Network	**Central**	<u>Quadrant 1</u> Standard unlikely to favor technologically In the short-term can buffer change by strong inter-firm complementary capability But risk of de-valuing this capability by supporting unfavorable technological change	<u>Quadrant 2</u> Standard likely to favor technologically Well positioned to capitalize on change by strong inter-firm complementary capability May enhance alliance position further in long-term as tech. change is favorable
	Peripheral	<u>Quadrant 3</u> Standard unlikely to favor technologically Weak inter-firm complementary capability limits ability to buffer from the change Challenging to strengthen inter-firm complementary capability as tech. change is unfavorable	<u>Quadrant 4</u> Standard likely to favor technologically But difficult to capitalize on change due to weak complementary capability May have opportunities to strengthen complementary capability as tech. change is favorable
		Peripheral	**Central**

Firm's Position in Technological knowledge interdependence network

Methodology

Data Sources and Sample

The data for this study came from a variety of different sources. Data on firms' memberships, their technical contributions in the standards committee, their balloting attendance and their strategic choices to support or contest the emerging consensus standard were all obtained from the standards committee's electronic database. I tracked firms' decisions in these committees from the time of their formation – 1994 - up until the year 2008.

Patent data to calculate firms' technological knowledge network positions were obtained from the NBER project (Hall, Jaffe and Trajtenberg, 2005). From the full patent dataset of more than 3 million patents, the sample of patents that matched the member firms of the technical subcommittees was extracted. This subset was further filtered by the technological categories and sub-categories that were relevant to the standards under consideration. These included HJT category 2 (Computers and Communications) with sub-categories 21 (Communications), Computer Hardware and Software (22), Computer Peripherals (23), Information Storage (24), Electronic business methods and software (25) and HJT category 4 (Electrical and Electronic) with sub-categories 41 (Electrical Devices), Measuring and Testing (43), Power Systems (45), Semiconductor Devices (46), Miscellaneous Electrical/Electronic (49). One limitation of using the NBER data is that only patent data up to 2006 are available and therefore technological positions calculated in 2007 and 2008 are right-truncated. However, in robustness checks, I found that limiting the sample to 2006 does not change the results.

Data to calculate firms’ strategic alliance network positions were obtained by searching Factiva for alliance announcements for each member firm. As Lavie (2007) and Schilling (2009) have shown in prior works, the SDC Platinum data on alliances covers only a small subset (less than 50%) of the alliance population and is therefore inappropriate to accurately construct an alliance network. By including all leading news sources, Factiva provides a more comprehensive dataset to track alliance announcements. One limitation of using Factiva is that it reports both rumored and actual alliances and often includes duplicate listings of the same alliance announcement from multiple media sources. I used a combination of manual and automated techniques to separate the duplicates and exclude rumored ties. Factiva also did not distinguish between technology development (R&D alliances) and technology licensing or distribution collaborations. However, my theoretical arguments in Hypotheses 2 and 3 that discuss the influence of firms’ complementary capabilities are focused mainly on the second type of alliance tie. I again used a combination of manual and automated techniques to parse the text in the description of the alliance announcements and categorize each alliance. Out of a total of 10389 alliances, I categorized 6490 as technology licensing or distribution collaborations and the remaining as R&D alliances.[7]

Next, data on firm financials, industry participation and mergers and acquisitions was obtained using a combination of Standard & Poor’s Compustat, Hoover’s,

[7] Alternative specifications with all alliances yielded substantively similar results.

BusinessWeek online, Corptech, Storagesearch.com and several other specialized media outlets that cover computer hardware, networking and peripherals sectors. Multiple data sources helped in not only triangulating the information but also, in several cases, supplementing the Compustat data that is restricted to publicly listed firms. Finally, I gathered data on firms' participation in a competing standards body (Universal Synchronous Bus – USB – Implementers' Forum) using the annual membership data from their archival sources.

Measures

Dependent variable. Firm's votes against passing the consensus standard: To capture a firm's opposition to the consensus standard, I used a count of the number of times a firm votes against unconditionally proceeding with the proposed standard in committee ballot measures, in a given year. Ballot measures are a mechanism by which firms vote whether or not to unconditionally proceed with the current version of the proposed standard's technological specifications. Although most standards consortia formally adopt a two-thirds majority rule (or simple majority in some cases), specific objections of firms that contest the standard typically need to be addressed before the development can proceed. A standards committee that chooses to progress despite outstanding concerns, faces a legitimacy issue and runs the risk that firms may drop out of standards deliberations or join a competing consortium (cf. Garud et al, 2002). By not voting for the unconditional progress of the standard to the next stage of development, firms may thus be able to delay the emergence of new technological rules that drive the direction of technological investment and market acceptance. They may do so either by declining the passage of the standard and/or by requesting several hundred changes to the specifications.

Independent variables. Variables, measures and data sources are listed in Table 1.

TABLE 1: Essay One. Variables, measures and data sources

Variable Name	Measure	Data source
Technological knowledge network centrality	In-degree centrality in a directed patent citations network of member firms (five year moving window)	NBER patent data
Strategic alliance network centrality	Degree centrality in an undirected strategic alliance network of member firms, with edges weighted by number of distinct ties between firms (five year moving window)	Factiva for alliance announcements
Balloting rate	Yearly count of number of ballots casted	INCITS database
Proposals authored	Yearly count of number of technical proposals authored by firm's engineers	INCITS database
Tenure on Standards alliance	Time elapsed in years since firm first joined the standards alliance	INCITS database
Total Patent stock	Five year stock of firm's patents	NBER patent data
Diversity of Patent stock	Number of distinct technological classes reflected in firm's patent stock	NBER patent data
External Citations to Patent stock	Number of citations to firm's patent stock from patents not owned by member firms	NBER patent data
Diversity of Ext Citations to Patent stock	Number of distinct technological classes reflected in patents that cite the firm's patents and are not owned by members	NBER patent data
Knowledge insularity (Self-citations)	Number of citations firm makes to own patents	NBER patent data
Technological opportunity	Sum of firm's patenting activity in different technological classes weighted by overall patenting intensity in these classes	NBER patent data
Density of patent network	Proportion of total possible patent linkages that exist	NBER and INCITS database
Alliances to firms outside standards	Yearly count of alliances to non-members	Factiva

Variable Name	Measure	Data source
(Table continued) Membership in competing standard	Flag indicating USB standard membership	USB-Implementers Forum
Size in Assets	Asset base in $ bn	Compustat, Hoovers, Corptech
Size in Revenues	Revenues in $ bn	Compustat, Hoovers, Corptech
Capital spend	Capital expenditure in $bn	Compustat
Financial slack in Cash	Cash in $bn	Compustat
Financial slack in long term debt	Debt in $bn	Compustat
Financial Performance (Net Income)	Net income in $bn	Compustat
Market share in sector (revenues)	Proportion of sector's revenues (sector defined by primary 4 digit SIC)	Compustat, Hoovers, Corptech
Investment share in sector (assets)	Proportion of sector's asset (sector defined by primary 4 digit SIC)	Compustat, Hoovers, Corptech
Overall sector size (assets)	Assets in $bn cumulated across firms in primary 4-digit SIC of firm	Compustat, Hoovers, Corptech

Technological knowledge network position: To compute this position, I used the NBER patent data to construct a technological network of patent citations. I used a five-year moving window of patent citations to derive this network. For example, for the year 1994, the citations network for patent citations from 1989 to 1993 was constructed. For the year 1995, the window begins in 1990 and ends in 1994.

The citations network was constructed in a three step iterative process. First, patent data for each member firm was obtained from the NBER database, beginning with the earliest available year (1975). Then, for each patent, all the citing patents were derived for each year in each of the moving windows. The assignee names for each of these citing patents were matched with the member firms, as the variable of interest is *within*- committee technological linkages. A technological network linkage between firm ‘i’ and firm ‘j’ is defined in year ‘t’ if at least one patent of firm ‘i’ was cited by at least one patent of firm ‘j’ in any year from ‘t-5’ through ‘t-1’ and if both firm ‘i' and firm ‘j’ are members of the standards sub-committee in year ‘t’. I constructed these linkages separately for each subcommittee (T10, T11 and T13) as each sub-committee maintains a separate membership roster and all firms are not members of all subcommittees. Patent application year (rather than patent grant year) was used for the citing patent since the linkage can be considered to be established once the patent application is submitted. Finally, this list of network links was input to network analysis software (Borgatti et al, 2002; Miura, 2012) and a centrality measure was calculated for each firm. This process was repeated for each of the moving windows corresponding to the years 1994 through 2008. Since patent citations are unidirectional, I treated the resultant network graphs as directed adjacency matrices and used the *in-degree centrality* measure.

Strategic alliance network position: To compute this position, I used the Factiva alliance data of technology licensing and distribution collaborations. The alliance network was derived on the same lines as the technological citations network, using the same lengths for time windows, the co-membership criteria and a *degree centrality* measure. However, there were three additional considerations for constructing the alliance network. First, alliances with more than two member firms were elaborated to include all dyadic tie combinations amongst the participating firms before computing the centrality measures. Second, the alliance network was coded as a symmetric bi-directional network as strategic alliances are generally treated as reciprocated relationships in the literature. Finally, I used the number of ties between two firms as the edge-weight to calculate the degree centrality. This allowed me to accurately reflect both the breadth *and* the depth of existing collaborations in firms' alliance network positions.[8]

<u>Interaction between Technological network position and Alliance network position:</u> A mean-centered interaction term of the technological network position variable and the alliance network position variable was computed for every member firm for every year in the sample.

Controls

Firms' tendencies to oppose or support the standard may be influenced by factors other than the hypothesized predictors. I use a number of controls to rule out these alternate hypotheses. First, firm's tendency to contest the standard may also depend upon its overall rate of attending and voting in the meetings in which these measures are proposed. I capture this tendency in the variable *Balloting rate*. Second, I control for the number of *Proposals authored* by the firms' engineers as this involvement may reflect a time commitment or sunk investment on the part of the firm that affects its voting behavior. Third, I control for *Tenure on Standards alliance* by calculating the number of years elapsed since the firm first joined the standards body. Although unlikely, firms with

[8] Although a weighted technological network could have been constructed using number of patent citations or number of patents cited as weights, I chose to use a binary approach as several scholars (notably Alcacer and Gittelman (2006)) have suggested that using citation count or patent count to measure knowledge flows suffers from examiner added bias.

higher tenure may be able to gain leadership positions on task committees and influence the decision-making process. Firms that join the standards body in the early years may also have made technological investments that are aligned with the standard. Fourth, the nature of a firm's proprietary technological investments may affect its opposition to the consensus standard independent of its position in technological and alliance networks. I included several measures to control for the breadth, depth and insularity of these investments. These variables are *Total Patent stock*, *Diversity of Patent stock, External Citations to Patent stock*, *Diversity of Ext Citations to Patent stock* and *Knowledge insularity (Self-citations)* and their construction is described in greater detail in Table 1. These are calculated using five year windows. Fifth, a firm's strategic decisions within standards committees could be shaped by its technological opportunity set or competitive pressures (e.g. Ahuja, 2000; Stuart, 1998). Firms with more liberal opportunities may be less resistant to the standard than firms that occupy competitive niches. To reflect such tendencies, I computed the variable *Technological opportunity*, using the method described by Ahuja (2000) and the variable *Overall sector size (assets)*, using a simple sum of the assets of all publicly listed firms in the firm's primary 4-digit SIC code. I also controlled for the number of *Alliances to firms outside standards* as well as *Membership in competing standard* as these might influence firms' voting patterns (cf. Leiponen, 2008). Finally, I use a number of accounting measures to control for firm size, slack and performance. These include *Size in Assets, Size in Revenues, Capital spend, Financial slack in long term debt,* and *Financial Performance (Net Income).* I also control for a firm's competitive market position in the variable *Market share in sector (revenues).*

Methods

I model the data as an unbalanced panel as membership in the subcommittees varies over the years. I use firm-subcommittee fixed-effects models to control for unobserved heterogeneity (Woolridge, 2003). I chose fixed effects models over random-effects models because the latter assume that the unobserved heterogeneity is uncorrelated with the variables of interest. This assumption may not be tenable if there are invariant, unobserved firm characteristics which are correlated with the firm's technological and/or alliance network position, as well as its tendency to support or oppose the standard. For example, firms that choose to actively patent and have technological knowledge collaborations with other firms (potentially resulting in a more central technological network position) may also choose to generally support a shared standards development program. By using firm-fixed effects models, I can control for these unobserved characteristics to the extent that they are time invariant.[9]

However, as firm fixed-effects models condition on within-firm variation only, I also conducted robustness checks with random-effects models and found no substantive differences in the results. Finally, I lag the independent variables and controls by one year to rule out simultaneity or reverse-causality effects (with the exception of *Balloting rate* that needs to reflect the same time period as the dependent variable).

The nature of the dependent variable (count) implies a Poisson process. However, over-dispersion (standard deviation is approximately twice the mean) implies that a

[9] Firm fixed effects models also automatically include time invariant effects specific to the sector or industry

negative binomial specification is more appropriate to model the data. However, a conditional fixed-effects negative binomial model is not a true fixed-effects model since it fails to control for all its predictors (Allison & Waterman, 2002; Hilbe, 2011). I therefore use conditional fixed-effects quasi-maximum likelihood Poisson regressions with robust standard errors to account for the overdispersion (Simcoe, 2007).[10]

Results

Table 2 lists the sample statistics and correlations. This table shows that multicollinearity could be a potential concern as there is a moderate correlation between the two network centrality variables. I provide more details on the multicollinearity checks following a discussion of the main results.

TABLE 2: Essay One. Descriptive statistics and correlations

#	**Variable Name**	**Mean**	**S.D.**	**1**	**2**	**3**	**4**
1	Voting against standard (DV)	0.76	1.49	1			
2	Balloting rate	6.46	5.51	0.31	1		
3	Proposals authored	0.65	1.58	0.38	0.21	1	
4	Tenure on Standards alliance	7.2	4.07	0.11	0.06	-0.04	1
5	Total Patent stock	2061.21	2964.54	0.12	-0.01	0.15	0.26
6	Diversity of Patent stock	48.11	26.51	-0.05	-0.03	0.05	0.17
7	External Citations to Patent stock	20260.33	31593.55	0.1	0.09	0.09	0.29
8	Diversity of Ext Citations to Patent stock	139.5	87.95	-0.06	0.07	-0.02	0.31
9	Knowledge insularity (Self-citations)	3297.63	6510.57	0.16	0.06	0.17	0.25
10	Technological opportunity	105391.06	164698.6	0.09	0	0.08	0.06
11	Density of patent network	0.18	0.1	-0.12	-0.31	-0.17	0.02
12	Alliances to firms outside standards	11.04	32.52	0.13	0.03	0.09	0.17
13	Membership in competing standard	0.46	0.5	0.01	0.06	-0.06	0.62
14	Size in Assets	23.8	28.95	0.03	0.09	0.04	0.24

[10] Negative binomial models yield substantively similar results

#	Variable Name	Mean	S.D.	1	2	3	4
15	Size in Revenues	18.84	24.02	0.08	0.1	0.08	0.28
16	Capital spend	1.34	1.77	0	0.07	0.06	0.19
17	Financial slack in Cash	2.57	3.29	0.05	0.08	0.05	0.25
18	Financial slack in long term debt	2.93	4.47	-0.01	0.1	0.01	0.16
19	Financial Performance (Net Income)	0.96	2.59	0.08	-0.03	0.07	0.23
20	Market share in sector (revenues)	0.22	0.21	0.07	0.08	0.04	0.15
21	Investment share in sector (assets)	0.24	0.24	0.02	0.11	0	0.08
22	Overall sector size (assets)	111.54	121.14	-0.06	-0.06	-0.01	0.17
23	Technological network centrality	0.62	0.23	-0.11	-0.05	-0.04	0.33
24	Strategic alliance network centrality	0.72	1.08	0.13	0	0.08	0.32

#	Variable Name	5	6	7	8	9	10	11	12
5	Total Patent stock	1							
6	Diversity of Patent stock	0.7	1						
7	External Citations to Patent stock	0.87	0.57	1					
8	Diversity of Ext Citations to Patent stock	0.65	0.81	0.75	1				
9	Knowledge insularity (Self-citations)	0.9	0.49	0.92	0.59	1			
10	Technological opportunity	0.73	0.53	0.63	0.47	0.63	1		
11	Density of patent network	0.1	0.02	0.13	0.05	0.1	0.12	1	
12	Alliances to firms outside standards	0.61	0.26	0.64	0.3	0.69	0.36	0.09	1
13	Membership in competing standard	0.25	0.25	0.28	0.32	0.2	0.16	0.1	0.23
14	Size in Assets	0.67	0.64	0.77	0.79	0.7	0.4	0.06	0.5
15	Size in Revenues	0.65	0.59	0.78	0.77	0.72	0.37	0.03	0.48
16	Capital spend	0.65	0.62	0.72	0.73	0.67	0.44	0.07	0.31
17	Financial slack in Cash	0.46	0.54	0.54	0.64	0.47	0.2	0.04	0.33
18	Financial slack in long term debt	0.68	0.57	0.81	0.76	0.71	0.46	0.07	0.36
19	Financial Performance (Net Income)	0.48	0.29	0.43	0.25	0.52	0.24	0.05	0.61
20	Market share in sector (revenues)	0.36	0.42	0.43	0.53	0.46	0.22	-0.05	0.26
21	Investment share in sector (assets)	0.37	0.46	0.42	0.56	0.41	0.21	-0.06	0.19
22	Overall sector size (assets)	0.29	0.36	0.26	0.31	0.19	0.19	-0.01	0.18
23	Technological network centrality	0.52	0.72	0.55	0.79	0.45	0.31	0.34	0.27
24	Strategic alliance network centrality	0.53	0.39	0.54	0.39	0.56	0.21	0.15	0.7

#	**Variable Name**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
13	Membership in competing standard	1											
14	Size in Assets	0.25	1										
15	Size in Revenues	0.23	0.94	1									
16	Capital spend	0.17	0.86	0.82	1								
17	Financial slack in Cash	0.25	0.85	0.8	0.7	1							
18	Financial slack in long term debt	0.13	0.84	0.81	0.75	0.59	1						
19	Financial Performance	0.2	0.5	0.47	0.44	0.44	0.21	1					
20	Market share in sector (revenues)	0.18	0.63	0.67	0.52	0.55	0.54	0.27	1				
21	Investment share in sector (assets)	0.1	0.67	0.63	0.55	0.59	0.6	0.2	0.91	1			
22	Overall sector size (assets)	0.21	0.38	0.32	0.35	0.3	0.27	0.27	-0.08	-0.1	1		
23	Technological network centrality	0.38	0.59	0.59	0.55	0.54	0.51	0.28	0.38	0.39	0.22	1	
24	Strategic alliance network centrality	0.33	0.63	0.61	0.46	0.62	0.34	0.67	0.36	0.31	0.21	0.45	1

Tables 3 and 4 display the results of the main regressions used to test the hypotheses. In the models in Table 3 (Models 1 to 6), I excluded nodes that were disconnected from the technological and alliance networks from the regressions. In the models in Table 4 (Models 7 to 12), I assigned a zero value for the centrality measure if a firm was not connected into the network. The difference between the two is 22 firms.

Models 1 and 7 include only the hypothesized variables and no controls. Models 2 and 8 include only the control variables and not the hypothesized variables. All the other models show the results from the step-wise addition of independent variables to the controls-only model.

TABLE 3: Essay One. Results for Hypothesis tests. Firm Fixed-effects Poisson models excluding disconnected nodes.

Dependent variable is Rate of Firm's voting against proceeding unconditionally with standard in a subcommittee in a given year. All models exclude disconnected nodes.

VARIABLES MODELS	(1)	(2)	(3)
Technological network centrality	-3.5544***		-3.1347***
	(0.9430)		(1.1303)
Strategic alliance network centrality	0.6518***		
	(0.1446)		
Technological centrality X Alliance centrality	-1.6685***		
	(0.4092)		
CONTROLS			
Balloting rate		0.0584***	0.0551***
		(0.0146)	(0.0160)
Proposals authored		0.0143	0.0085
		(0.0384)	(0.0353)
Tenure on Standards alliance		-0.0585	-0.0249
		(0.0382)	(0.0418)
Total Patent stock		0.0004*	0.0004*
		(0.0002)	(0.0002)
Diversity of Patent stock		0.0213	0.0316
		(0.0218)	(0.0202)
External Citations to Patent stock		0.0000**	0.0000
		(0.0000)	(0.0000)
Diversity of Ext Citations to Patent stock		-0.0097	-0.0052
		(0.0075)	(0.0073)
Knowledge insularity (Self-citations)		-0.0002**	-0.0001**
		(0.0001)	(0.0001)
Technological opportunity		0.0000	-0.0000
		(0.0000)	(0.0000)
Density of patent network		-1.0469	0.6523
		(2.4902)	(2.6117)
Alliances to firms outside standards		-0.0046	-0.0027
		(0.0045)	(0.0047)
Membership in competing standard		-0.1731	-0.0690
		(0.2887)	(0.2848)
Size in Assets		-0.0061	-0.0103
		(0.0143)	(0.0141)
Size in Revenues		0.0158	0.0173
		(0.0184)	(0.0188)
Capital spend		-0.2353*	-0.2189*

VARIABLES	MODELS (1)	(2)	(3)
		(0.0514)	(0.0506)
Financial slack in long term debt		-0.0765	-0.0909
		(0.0697)	(0.0700)
Financial Performance (Net Income)		0.0018	0.0075
		(0.0284)	(0.0292)
Market share in sector (revenues)		0.8520	0.1203
		(1.0297)	(1.0360)
Investment share in sector (assets)		4.0783***	4.7860***
		(1.4553)	(1.4140)
Overall sector size (assets)		0.0092***	0.0095***
		(0.0035)	(0.0032)
Firm - subcommittee fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Observations	564	564	564
Number of groups	79	79	79
Log likelihood	-480.6	-447.7	-442.2
Chi-square	24.49	276.1	302.1

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

MODELS VARIABLES	(4)	(5)	(6)
Technological network centrality		-3.1755***	-3.7600***
		(1.0743)	(1.1512)
Strategic alliance network centrality	0.4710***	0.4792***	0.6497***
	(0.1364)	(0.1375)	(0.1731)
Technological centrality X Alliance centrality			-1.0501** (0.4790)
CONTROLS			
Balloting rate	0.0515***	0.0479***	0.0416***
	(0.0143)	(0.0158)	(0.0158)
Proposals authored	0.0149	0.0093	0.0072
	(0.0374)	(0.0345)	(0.0339)
Tenure on Standards alliance	-0.0852**	-0.0515	-0.0783**
	(0.0357)	(0.0367)	(0.0392)
Total Patent stock	0.0005**	0.0004**	0.0004**
	(0.0002)	(0.0002)	(0.0002)
Diversity of Patent stock	0.0084	0.0188	0.0154
	(0.0222)	(0.0197)	(0.0197)

(Table continued) VARIABLES	MODELS (4)	(5)	(6)
External Citations to Patent stock	0.0000	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)
Diversity of Ext Citations to Patent stock	-0.0052	-0.0005	0.0011
	(0.0082)	(0.0077)	(0.0076)
Knowledge insularity (Self-citations)	-0.0001*	-0.0001	-0.0001*
	(0.0001)	(0.0001)	(0.0001)
Technological opportunity	0.0000	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)
Density of patent network	-1.3211	0.3663	0.5654
	(2.4305)	(2.5245)	(2.5777)
Alliances to firms outside standards	-0.0068*	-0.0048	-0.0044
	(0.0040)	(0.0042)	(0.0042)
Membership in competing standard	-0.4005	-0.3084	-0.2180
	(0.3001)	(0.2923)	(0.2914)
Size in Assets	-0.0142	-0.0185	-0.0155
	(0.0141)	(0.0137)	(0.0136)
Size in Revenues	0.0071	0.0085	0.0149
	(0.0162)	(0.0165)	(0.0177)
Capital spend	-0.1558	-0.1400	-0.1856
	(0.0528)	(0.0521)	(0.0536)
Financial slack in long term debt	-0.0889	-0.1019	-0.1170*
	(0.0652)	(0.0643)	(0.0670)
Financial Performance (Net Income)	0.0043	0.0099	0.0152
	(0.0304)	(0.0315)	(0.0321)
Market share in sector (revenues)	1.2671	0.5105	0.1499
	(1.0504)	(1.0633)	(1.1258)
Investment share in sector (assets)	4.1807***	4.9173***	4.9187***
	(1.5042)	(1.4781)	(1.4864)
Overall sector size (assets)	0.0119***	0.0122***	0.0118***
	(0.0038)	(0.0035)	(0.0035)
Firm and subcommittee fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Observations	564	564	564
Number of groups	79	79	79
Log likelihood	-442.8	-437.1	-435.2
Chi-square	228.1	270.3	331.6

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

TABLE 4: Essay One. Results for Hypothesis tests. Firm Fixed-effects Poisson models including disconnected nodes.

Dependent variable is Rate of Firm's voting against proceeding unconditionally with standard in a subcommittee in a given year. All models *include* disconnected nodes.

VARIABLES	Model 7	Model 8	Model 9
Technological network centrality	-3.2544***		-3.5031***
	(0.8027)		(0.9425)
Strategic alliance network centrality	0.8572***		
	(0.1595)		
Technological centrality X Alliance centrality	-1.8985***		
	(0.3881)		
CONTROLS			
Balloting rate		0.0725***	0.0720***
		(0.0136)	(0.0143)
Proposals authored		0.0379	0.0276
		(0.0348)	(0.0304)
Tenure on Standards alliance		-0.0112	0.0220
		(0.0346)	(0.0355)
Total Patent stock		0.0003	0.0002
		(0.0002)	(0.0002)
Diversity of Patent stock		0.0190	0.0307
		(0.0208)	(0.0197)
External Citations to Patent stock		0.0000***	0.0000**
		(0.0000)	(0.0000)
Diversity of Ext Citations to Patent stock		-0.0111	-0.0079
		(0.0071)	(0.0070)
Knowledge insularity (Self-citations)		-0.0001**	-0.0001*
		(0.0001)	(0.0001)
Technological opportunity		0.0000	-0.0000
		(0.0000)	(0.0000)
Density of patent network		-0.5892	1.3279
		(1.8534)	(1.9131)
Alliances to firms outside standards		-0.0050	-0.0035
		(0.0041)	(0.0044)
Membership in competing standard		-0.0830	-0.0704
		(0.2316)	(0.2306)
Size in Assets		0.0188	0.0096
		(0.0146)	(0.0145)
Size in Revenues		-0.0034	0.0021
		(0.0169)	(0.0175)
Capital spend		-0.1073	-0.1116
		(0.1261)	(0.1221)

(Table continued) VARIABLES	MODELS	Model 7	Model 8	Model 9
Financial slack in Cash			-0.1019**	-0.1073**
			(0.0469)	(0.0466)
Financial slack in long term debt			-0.0191	-0.0097
			(0.0385)	(0.0433)
Financial Performance (Net Income)			0.0182	0.0241
			(0.0228)	(0.0224)
Market share in sector (revenues)			2.1243**	1.3135
			(1.0827)	(1.0165)
Investment share in sector (assets)			1.9009	3.1459***
			(1.1659)	(1.0745)
Overall sector size (assets)			0.0024	0.0042**
			(0.0021)	(0.0019)
Firm and sub-committee fixed effects		Yes	Yes	Yes
Industry (sector) fixed effects		Yes	Yes	Yes
Observations		792	792	792
Number of groups		101	101	101
Log likelihood		-664.6	-621.2	-611.5
Chi-square		35.19	165.8	203.2

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

VARIABLES	Model 10	Model 11	Model 12
Technological network centrality		-3.5709***	-3.9079***
		(0.9449)	(0.9868)
Strategic alliance network centrality	0.2954**	0.3182**	0.5421***
	(0.1226)	(0.1276)	(0.1873)
Technological centrality X Alliance centrality			-0.9360**
			(0.4509)
CONTROLS			
Balloting rate	0.0689***	0.0681***	0.0633***
	(0.0135)	(0.0141)	(0.0141)
Proposals authored	0.0389	0.0285	0.0250
	(0.0337)	(0.0293)	(0.0293)
Tenure on Standards alliance	-0.0260	0.0061	-0.0148
	(0.0344)	(0.0344)	(0.0364)
Total Patent stock	0.0003	0.0002	0.0002
	(0.0002)	(0.0002)	(0.0002)
Diversity of Patent stock	0.0126	0.0240	0.0211
	(0.0209)	(0.0195)	(0.0195)
External Citations to Patent stock	0.0000*	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)

VARIABLES (Table continued)	Model 10	Model 11	Model 12
Diversity of Ext Citations to Patent stock	-0.0090	-0.0054	-0.0035
	(0.0073)	(0.0072)	(0.0073)
Knowledge insularity (Self-citations)	-0.0001*	-0.0001	-0.0001
	(0.0001)	(0.0001)	(0.0001)
Technological opportunity	0.0000	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)
Density of patent network	-0.6132	1.3445	1.4094
	(1.7991)	(1.8721)	(1.9000)
Alliances to firms outside standards	-0.0070*	-0.0055	-0.0050
	(0.0038)	(0.0040)	(0.0040)
Membership in competing standard	-0.1823	-0.1818	-0.1301
	(0.2407)	(0.2373)	(0.2311)
Size in Assets	0.0152	0.0054	0.0093
	(0.0143)	(0.0140)	(0.0139)
Size in Revenues	-0.0085	-0.0033	0.0007
	(0.0153)	(0.0160)	(0.0165)
Capital spend	-0.0511	-0.0527	-0.0853
	(0.1227)	(0.1211)	(0.1176)
Financial slack in Cash	-0.1108**	-0.1173**	-0.1174**
	(0.0475)	(0.0474)	(0.0486)
Financial slack in long term debt	-0.0133	-0.0028	-0.0128
	(0.0368)	(0.0409)	(0.0429)
Financial Performance (Net Income)	0.0235	0.0295	0.0337
	(0.0240)	(0.0238)	(0.0246)
Market share in sector (revenues)	2.3545**	1.5370	1.4170
	(1.0826)	(1.0224)	(1.0129)
Investment share in sector (assets)	1.9051	3.1876***	3.0623***
	(1.1609)	(1.0787)	(1.0649)
Overall sector size (assets)	0.0032	0.0050**	0.0047**
	(0.0022)	(0.0020)	(0.0020)
Firm and sub-committee fixed effects	Yes	Yes	Yes
Industry (sector) fixed effects	Yes	Yes	Yes
Observations	792	792	792
Number of groups	101	101	101
Log likelihood	-618.8	-608.9	-607.1
Chi-square	170.0	222.6	268.7

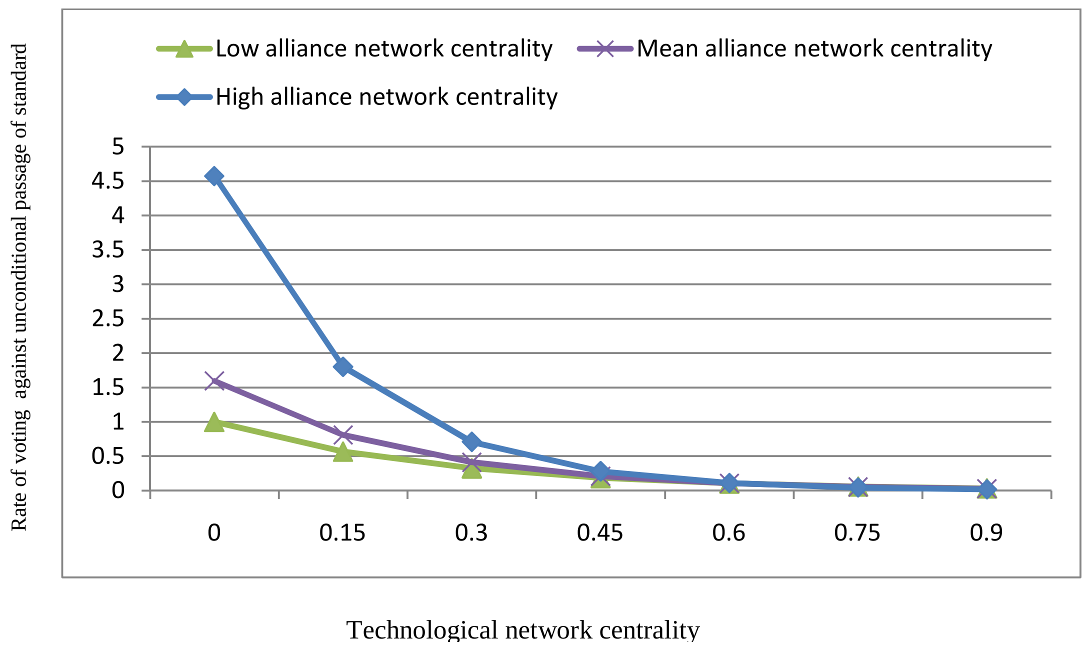
Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

As the dependent variable is a yearly count of votes *against* unconditionally proceeding with the standard, a negative coefficient for a variable in a regression would indicate *support* for the standard and a positive coefficient for a variable would indicate *opposition* to the standard. Hypothesis 1 stated that the more central a focal firm is within the technological knowledge network of participating member firms, the lower its rate of opposition to the standard will be. The coefficient of the variable *Technological network centrality* is negative and strongly significant in all partial and full models indicating support for Hypothesis 1. Hypothesis 2 stated that the more central a focal firm is within the strategic alliance network of participating member firms, the higher its rate of opposition to the standard will be. The results show that the coefficient for the variable *Strategic alliance network centrality* is positive and strongly significant in all partial and full models, indicating that Hypothesis 2 is supported.

Finally, Hypothesis 3 stated that the more central a focal firm's technological knowledge network position, the less positive the effect of its strategic alliance network position on its rate of opposition to the standard. The coefficient for the interaction term *Technological centrality X Alliance centrality* is negative and significant in all partial and full models, indicating that Hypothesis 3 is well-supported.

Figure 2 shows a graph depicting this interaction. The X-axis indicates the *Technological network centrality* and the Y-axis indicates *Rate of opposition to the standard* (dependent variable). Three separate plots are shown, corresponding to High, Mean and Low *Alliance network centrality* (the difference between Low and High in this case is taken as three standard deviations). Both the independent and joint effects of the two networks are strongly manifested in the plots. At low levels of *Technological network centrality*, the opposing effect of a firm with High *Alliance network centrality* on the coordination of the standard is almost five times the opposing effect of a firm with Low *Alliance network centrality*. However, at high levels of *Technological network centrality* there is barely any perceptible difference between these firms – in particular, the opposing effect of the High *Alliance network centrality* is almost completely nullified at High *Technological network centrality* levels.

Figure 3: Interaction between technological & alliance centrality (Essay One)



<u>*Robustness checks*</u>

Since multicollinearity could be a potential concern, I evaluated the variance inflation factors (estat vif command in STATA) after executing an OLS regression and found that there were no independent variables that had a high inflation factor (>10). In particular, the primary independent variables – *Technological network position* and

Alliance network position – both had VIF's under five despite a moderate correlation between them. As an additional check, I also randomly omitted 20% of the observations in the sample and repeated this procedure 200 times to create 200 different subsamples. I then ran regressions on each of these subsamples to assess whether multicollinearity rendered the results sensitive to sampling changes. These sensitivity analyses provided strong support for the results and significantly alleviated multicollinearity concerns. I also checked for within-panel correlations using the *xtserial* command in STATA (Drukker, 2003). The panel shows autocorrelation that justifies the use of clustered robust standard errors in the fixed-effects models. I carried out a number of additional robustness checks to test the sensitivity of my empirical assumptions. Table 5 shows the results of selected robustness regressions. These results validate that the main models are reasonably robust to changes in measures, model specifications and estimation techniques. Model 13 shows the results of a regression with the sample truncated at 2006 to assess sensitivity to the right-censoring of the NBER patent dataset. Model 14 shows the results of a regression with a double lag for *Technological network* centrality. In Model 15, the dependent variable is modeled as a proportion of firms' votes against the standard instead of a simple count. This allows me to capture both the original dependent variable and *Balloting rate* in one measure and use a panel OLS model instead of a non-linear model. Models 16 and 17 assess sensitivity to missing financial data by omitting these variables and including public firm indicator variable. Finally, Model 18 shows the results of a random effects Poisson model with industry controls. This model includes the firms that drop out of the fixed effects regression either because they were present on the standards body for exactly one year or because they had no variation in the dependent variable (for example if they never contested the standard in any ballot).

TABLE 5: Essay One. Results for Hypotheses tests. Alternate models.

VARIABLES	Model 13	Model 14	Model 15
Technological network centrality	-4.1094***	-3.0018***	-0.4338***
	(1.2131)	(0.9759)	(0.1594)
Strategic alliance network centrality	0.7354***	0.8006***	0.2036***
	(0.1839)	(0.2084)	(0.0593)
Technological centrality X Alliance centrality	-1.2335**	-1.0684*	-0.3138***
	(0.5186)	(0.5582)	(0.1197)
CONTROLS			
Balloting rate	0.0435***	0.0589***	-0.0069**
	(0.0160)	(0.0160)	(0.0027)
Proposals authored	0.0060	-0.0035	-0.0083
	(0.0333)	(0.0403)	(0.0100)
Tenure on Standards alliance	-0.0942**	-0.0699*	0.0025
	(0.0457)	(0.0419)	(0.0062)
Total Patent stock	0.0005**	0.0005***	0.0001**
	(0.0002)	(0.0002)	(0.0000)
Diversity of Patent stock	0.0133	0.0195	0.0028
	(0.0207)	(0.0215)	(0.0037)
External Citations to Patent stock	0.0000	0.0000*	0.0000
	(0.0000)	(0.0000)	(0.0000)
Diversity of Ext Citations to Patent stock	0.0040	-0.0073	-0.0019
	(0.0078)	(0.0080)	(0.0016)
Knowledge insularity (Self-citations)	-0.0001	-0.0001**	-0.0000
	(0.0001)	(0.0001)	(0.0000)
Technological opportunity	-0.0000	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)
Density of patent network	0.5930	-1.7252	0.3290
	(3.0444)	(2.7286)	(0.3642)
Alliances to firms outside standards	-0.0057	-0.0101**	-0.0011
	(0.0042)	(0.0051)	(0.0010)
Membership in competing standard	-0.2720	0.0226	-0.0150
	(0.3066)	(0.2908)	(0.0363)
Size in Assets	-0.0170	-0.0203	-0.0050
	(0.0146)	(0.0132)	(0.0034)
Size in Revenues	0.0187	0.0096	0.0051
	(0.0192)	(0.0172)	(0.0035)
Capital spend	-0.1914	-0.2099*	-0.0216
	(0.1288)	(0.1198)	(0.0164)
Financial slack in Cash	-0.1120**	-0.0697	0.0030
	(0.0555)	(0.0579)	(0.0097)
Financial slack in long term debt	-0.1061	-0.1155**	-0.0080
	(0.0685)	(0.0581)	(0.0086)

VARIABLES (Table 4 continued)	Model 13	Model 14	Model 15
Financial Performance (Net Income)	0.0137	0.0283	0.0042
	(0.0333)	(0.0347)	(0.0053)
Market share in sector (revenues)	0.1263	0.8792	-0.1599
	(1.2112)	(1.1323)	(0.2039)
Investment share in sector (assets)	4.7422***	4.1082**	0.4960
	(1.6178)	(1.7114)	(0.3194)
Overall sector size (assets)	0.0118***	0.0094**	0.0005
	(0.0035)	(0.0041)	(0.0006)
Constant			0.2331
			(0.2129)
Firm and sub-committee fixed effects	Yes	Yes	Yes
Industry (sector) fixed effects	Yes	Yes	Yes
Observations	541	490	566
Number of groups	79	73	118
Log likelihood	-417.8	-376.6	N/A
Chi-square	223.3	533.8	N/A
R-squared	N/A	N/A	0.1453

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

	MODELS		
VARIABLES	Model 16	Model 17	Model 18
Technological network centrality	-3.2822***	-3.0006***	-3.2085***
	(1.2052)	(0.9419)	(0.8381)
Strategic alliance network centrality	0.4970***	0.5121***	0.4642***
	(0.1669)	(0.1872)	(0.1539)
Technological centrality X Alliance centrality	-0.9691**	-0.9951**	-0.7719*
	(0.4900)	(0.4853)	(0.4566)
CONTROLS			
Balloting rate	0.0642***	0.0763***	0.0637***
	(0.0174)	(0.0154)	(0.0114)
Proposals authored	0.0176	0.0348	0.0412*
	(0.0338)	(0.0310)	(0.0241)
Tenure on Standards alliance	-0.0351	0.0193	-0.0171
	(0.0429)	(0.0399)	(0.0276)
Total Patent stock	0.0003*	0.0003*	0.0004***
	(0.0002)	(0.0002)	(0.0001)
Diversity of Patent stock	0.0198	0.0211	-0.0097
	(0.0210)	(0.0206)	(0.0130)
External Citations to Patent stock	0.0000	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)

(Table continued) VARIABLES	MODELS	Model 16	Model 17	Model 18
Diversity of Ext Citations to Patent stock		0.0012	-0.0072	0.0068
		(0.0072)	(0.0070)	(0.0046)
Knowledge insularity (Self-citations)		-0.0001	-0.0001*	-0.0001**
		(0.0001)	(0.0001)	(0.0001)
Technological opportunity		-0.0000	-0.0000	0.0000
		(0.0000)	(0.0000)	(0.0000)
Density of patent network		0.3773	1.1584	0.9619
		(2.6242)	(1.8350)	(1.2127)
Alliances to firms outside standards		-0.0047	-0.0042	-0.0046
		(0.0037)	(0.0036)	(0.0033)
Membership in competing standard		-0.0635	-0.1162	-0.2594
		(0.2860)	(0.2295)	(0.2048)
Size in Assets				-0.0166
				(0.0156)
Size in Revenues				0.0147
				(0.0139)
Capital spend				-0.1210
				(0.0801)
Financial slack in Cash				-0.0828*
				(0.0466)
Financial slack in long term debt				-0.1089**
				(0.0542)
Financial Performance (Net Income)				-0.0143
				(0.0325)
Market share in sector (revenues)				1.0544
				(1.0836)
Investment share in sector (assets)				2.5144**
				(1.1995)
Overall sector size (assets)				0.0094***
				(0.0029)
Constant				-3.3322***
				(1.2733)
Firm and sub-committee fixed effects		Yes	Yes	No
Industry (sector) fixed effects		Yes	Yes	Yes
Observations		564	792	714
Number of groups		79	101	138
Log likelihood		-452.7	-623.1	-675.9
Chi-square		126.7	114.9	190.9
R-squared		N/A	N/A	N/A

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In addition to these robustness checks, I also compared the values of the dependent and control variables for high alliance network centrality vs. low alliance network centrality firms, and then again for high technological network centrality vs. low technological network centrality firms. The sub-samples corresponding to these were defined as >75th percentile for high centrality and < 25th percentile for low centrality (peripheral), and means were calculated for the measures corresponding to these sub-samples. Table 6 illustrates the results of the t-test comparing the sub-samples across these measures. Column 3 gives the results of comparison between column 1 and column 2 (high vs. low alliance centrality firms), and column 6 gives the results of comparison between column 4 and column 5 (high vs. low tech. centrality firms).

TABLE 6: Essay One. Comparing the quadrants

Measure	Alliance Central (1)	Alliance Peripheral (2)	T-test (3)	Tech Central (4)	Tech Peripheral (5)	T-test (6)
Votes against (per year)	1.2	0.63	***	0.65	1.05	***
Balloting rate	7.1	5.7	**	6.3	6.8	ns
Number of technical proposals	0.99	0.42	***	0.66	0.65	ns
Number of engineers sent	2.1	1.41	***	1.75	1.65	ns
Year of joining	1994	1996	***	1994	1997	***
Patent stock (#)	4337	574	***	2655	288	***
Firm size ($bn)	51.1	6.8	***	30.2	4.6	***
Firm performance ($bn)	3.15	0.15	***	1.24	0.14	***
Market share	35.9%	15.4%	***	25.4%	10.1%	***
Industry size ($bn)	137.8	71.4	***	119.8	86.8	***

As the results in Column 6 show, there was no statistically significant difference between the technologically central and the technologically peripheral firms in either the rate at which they attend ballots, the level of their technical contributions in the standards committees or the number of engineers they assigned to serve on these committees. This alleviates the concern that perhaps the technologically peripheral players were represented less or that they chose to contribute less to the committee because they lacked the necessary knowledge. On the other hand, as the regression results had already established, technologically peripheral firms showed a significantly higher rate of opposition to the standard.

The converse is true for the comparisons between the high centrality alliance network firms and the low centrality alliance network firms. As Column 3 shows, although the central firms in the alliance network actually contributed a significantly higher number of proposals, sent more engineers and joined these standards bodies earlier, they still showed a significantly higher rate of opposition to the standard.

Discussion

A central concern in strategic management and organization theory research has been to understand how firms compete in highly uncertain environments characterized by technological flux (Henderson and Clark, 1990; Anderson and Tushman, 1990). Responding to this concern, one promising research direction has highlighted “dynamic capabilities” as a source of competitive advantage for firms that need to continually adapt and modify their resource bases in response to frequent technological shifts (Teece et al, 1997; Helfat et al, 2007; Winter, 2003). However, the ability of firms to systematically *control* or direct technological change in order to sustain or even enhance the value of their current resources and capabilities has not received similar attention (cf. Teece, 2007). This paper explores the characteristics of firms that are able to shape such change and the strategic choices they make in attempting to control change.

The standards consortia in this study are multi-firm organizational bodies where firms come together to draft industry standards, with a shared objective of reducing uncertainty around the nature of technological change. These standards constitute rules that prescribe how different components of a technical system should interact, and in the process also demarcate the functional behavior of specific components. Studying firm-level decision making within these settings allows the elaboration of the fundamental tension that firms have to manage in continuously changing environments. On the one hand, a firm needs to manage technological uncertainty by cooperatively participating in these multi-firm alliances, which equip it with essential knowledge to assess the direction of technological change. But the nature of change endorsed by the technical committee may increase the firm's risk for capability obsolescence if the standard does not build on the firm's knowledge or if it does not allow the firm to continue to exploit its complementary assets. Such tensions may be further aggravated if the mandated standard simultaneously enhances the value of competitors' capabilities. The results from this study show that these different considerations that affect firms' strategic decisions on whether to support or oppose the consensus standard are crucially affected and jointly determined by firms' resource positions in two salient strategic networks. Moreover, the findings suggest that each of the inter-organizational networks operates differently in the standards-setting context, thus emphasizing the importance of considering both the type of tie *and* the context when theorizing about the effect of networks on firms' conduct.

These results have several important implications. First, these results re-emphasize the importance of network structure in understanding firms' strategic choices in settings of technological uncertainty and change. Firms are embedded in structures of relationships that arise out of a series of path-dependent choices made by themselves as well as their competitors and complementors. These positions determine the extent of influence firms can wield directly or indirectly in such inter-firm deliberations. In this particular technological change setting, there is sufficient evidence that the pattern of linkages between firms' prior technological knowledge investments determines which firms can advantageously shape the standard. Firms will need to examine their positions in such networks vis-à-vis their peers before committing to the standards-setting process.

Second, the study brings to light how these decisions are shaped by firms' positions in *multiple* such structures, and more importantly how they are shaped by the *interaction* between these positions. Most network studies focus on a single structural context such as alliance networks and ignore the pluralism that firms embody (Shipilov and Li, 2010). In this standards-setting context, when only the alliance network is considered, centrality is found to have an opposing effect on the coordinated outcome. However, when both the alliance and the technological network centrality are considered, firms' actions suggest that they are more supportive of a coordinated outcome.

Third, the arguments and findings from this paper suggest that central players in networks may not be able to orchestrate decisions concerning the network in a technical standards context, where deliberations are rooted on technical excellence and conflicts are resolved around the core of technological knowledge. It thus highlights the importance of considering technological knowledge interdependencies when looking at how firms are likely to make choices in such alliances.

Finally, these findings highlight both the challenges and opportunities for firms in controlling technological change. Incumbent firms that are already central in the technological knowledge network begin with an advantage in standards discussions, but their ability to forge a consensus will also depend upon the technological knowledge network position of the firms who are more central in the strategic alliance network. On the other hand, the incumbent firms that have an advantageous alliance network resource need to carefully consider the shifts in the technological landscape as well – if these firms are not also embedded in the technological knowledge network, they may not be able to sustain the complementary asset advantages arising from their alliance network position. Although voting against the standard may delay its emergence and allow such firms to continue to exploit their complementary assets, this may devalue the social capital advantages of their network position as mistrust and haggling within the network increase with self-serving actions of firms.

For technologically peripheral firms in the network, their tangential knowledge puts them at a disadvantage in standards discussions. However, they may be able to leverage the need for the more central firms to expeditiously agree to a coordinated standard. As Garud et al (2002) point out with the example of Sun Microsystems, technologically central firms may face a ‘legitimacy trap’ if they attempt to push the standard through – they may be thus willing to make concessions with peripheral firms to achieve a broader consensus that enhances the legitimacy of the standards-setting process. Future studies could explore the nature of such concessions.

This study is not without limitations. This paper considers only two salient strategic networks as influencing firms’ conduct – in reality there even more inter-organizational relationships that firms are embedded in (e.g. the interpersonal networks of engineers who participate in the standards bodies) that may have some bearing in this context.

Contributions, Limitations and Future Research Directions

This study makes several important theoretical and empirical contributions to research on technological change, alliances and alliance networks. First, this paper contributes to an emerging stream of literature which suggests that the conduct of a firm is derived in part from the networks it participates in (Gulati, Nohria and Zaheer, 2000; Kogut, 2000). While prior studies have looked individually at implications of a firm’s position in a technological network (e.g. Stuart and Podolny, 1996) or its embeddedness in a relational network (e.g. Ahuja, 2000; Uzzi, 1997), this study proposes that firms’ strategic decisions in settings of technological change are enabled or constrained by the effects of its positions in *both* of these networks.

Second, this study attempts to shed light on an intriguing phenomenon, that in spite of the lack of a hierarchical governance structure to manage divergent private interests, multi-partner alliance consortia have emerged as the preferred mode for structuring an industry-wide response to the challenges of technological change. Additionally, this paper makes an empirical contribution by investigating a setting where firms have opportunities to *shape* change instead of adapting to change (Teece, 2007), and argues that these opportunities are in part driven by capabilities at the network level (Rothaermel and Hess, 2007).

Third, this paper contributes to our understanding of the decision-making dynamics within multi-firm alliances. Prior studies of alliances and alliance networks have focused on the formation and implications of dyadic ties, and this study builds upon this research by looking at how these ties influence firms' strategic choices in more complex settings that involve multiple firms. This paper also provides insights into how firms handle the conflicting pressures of cooperation and appropriation in multi-firm settings. Multi-firm standards consortia are settings which are inherently characterized by conflict as firms with divergent interests seek to forge common ground.

Finally, this paper establishes several promising avenues for future research. One such avenue to explore is the relationship between structural asymmetry of member firms and the extent of consensus across different multi-firm standards consortia - i.e. whether consortia that consist of member firms with wide variations in network positions are marked by less conflict than consortia where member firms are more structurally homogenous. Similarly, researchers could investigate whether the density of network ties influences consensus formation across different networks.

Second, an important question from a strategy standpoint is how firms benefit from their participation in these multi-firm alliances and in particular, what drives the heterogeneity of such benefits (e.g. Lavie et al, 2007). In this vein, it would be insightful to uncover the strategies less favored firms (on the technological network periphery for example) can undertake within these committees to improve their participation outcomes or network positions. For example, the mobility of engineers between firms that participate in these committees (Dokko and Rosenkopf, 2010), may affect the extent of interpersonal influence and the outcome of standards deliberations. Similarly, a nascent stream of research in strategy and entrepreneurship that has begun to explore ways by which firms that are at the periphery of a strategic network can form ties that make them more central (e.g. Rosenkopf and Padula, 2008; Ahuja, Polidoro and Mitchell, 2009), despite powerful effects of structural homophily and preferential attachment (Barabasi and Albert, 1999; Gulati, 1995b). The standards-setting context offers a rich venue to study how inter-firm interactions may shape such strategies of peripheral firms.

CHAPTER 4: ESSAY TWO - GIVE AND TAKE?

In Essay One, I found that peripheral firms in the technological knowledge network opposed the emerging standard while central firms supported it. Clearly contestation has one likely effect of delaying the emergence of the standard - as Simcoe (2012) points out, even small levels of conflict are enough to cause substantial delays in the productivity of voluntary standards-setting committees. Although technologically central firms that stand to benefit the most by the quick passage of the standard could ignore minority opposition, the process of resolution in voluntary standards committees mandates that member firms make all possible efforts to reach a consensus. This essay explores how such consensus-building efforts might take the shape of inter-firm relationship formation, as central firms look to increase the support and involvement of the peripheral players to build consensus and legitimacy for the standard, while the peripheral players attempt to offset the technological disadvantages that the standard poses by gaining strategic collaborations with central firms.

Background and motivation

With the last two decades witnessing substantial growth in alliance formation (cf. Gulati, 2007; cf. Gulati, Lavie and Singh, 2009), a substantial body of research has also evolved around studying both the *causes* and *consequences* of these inter-firm collaborations.

On the *benefits* side, this research has found that strategic alliances allow firms to overcome some of the challenges of technological change (Ahuja, 2000; Rothaermel, 2001). Firms may use these boundary-spanning relationships to counter local search tendencies and incorporate distant knowledge (Rosenkopf and Almeida, 2003), which may in turn improve their technical and financial performance (Ahuja, 2000; McEvily and Zaheer, 1999) and allow them to shape technological evolution (Rosenkopf and Nerkar, 2001). Alliances may also be construed as a form of legitimacy-enhancing endorsement in high-velocity environments, especially when startups are the beneficiaries of collaborative relationships with established and prominent partner firms (e.g. Stuart, Hoang and Hybels, 1999; Gulati and Higgins, 2003).

On the *causes* side, broadly two streams of research have developed. The first stream asks why some firms undertake more alliances either relative to other corporate development strategies (e.g. Robertson and Gatignon, 1998; Vanhaverbeke et al, 2002; Villalonga and McGahan, 2005) or relative to other firms (Eisenhardt and Schoonhoven, 1996; Gulati, 1999; Baum et al, 2000; Stuart, 2000). Several explanations including transaction cost theory, social capital, strategic uncertainty and technological resources have been proposed and tested. The second stream explores the specific characteristics of pairs of firms that increases their likelihood of entering into a collaborative relationship (e.g. Gulati and Gargiulo, 1999; Chung, Singh and Lee, 2000; Rosenkopf et al, 2001; Rosenkopf and Padula, 2008; Ahuja, Polidoro and Mitchell, 2009). This research has also postulated and tested several dyadic characteristics such as prior partnering experience (relational capital), resource complementarities (technological capital) and status or prominence (social capital) as drivers of alliance formation.

My arguments in this paper advance these research streams by investigating the drivers of alliance formation, both at the firm level and at the dyad level, as a consequence of firms' involvement in standards-setting committees. I build on a prior study by Rosenkopf et al (2001) who show that interactions between engineers in a standard-setting context may be a bottom-up driver of alliance formation. They show that these contexts function as social venues where firms' representatives can identify both opportunities and partners for collaboration. I take their findings a level deeper by exploring the heterogeneity of these ties *amongst* the member firms that are active in the standards committees. The large number of firms participating in these organizations, the divergence in member interests and consequently the challenges in governing these bodies all point towards potential asymmetries in how relational opportunities may accrue to these firms (Das and Teng, 2002; Lavie et al, 2007), and I build theory to identify the nature of these asymmetries.

While prior research has demonstrated that participation by firms in standard-setting committees does in fact lead to future alliances (Rosenkopf et al, 2001), it has not explored whether and how the *nature* and *extent* of participation within these committees, affects the heterogeneity of such opportunities, and particularly on the ability of a firm to forge relationships with central players in the alliance network (e.g. Ahuja, Polidoro and Mitchell, 2009). Research has also not considered how a firm’s participation over time affects its ability to garner benefits. Since most large technical consortia are multi-year joint efforts where consensus evolves gradually with successive versions of standards being drafted and debated, analyzing these settings using a longitudinal lens is likely to be insightful.

My arguments in this paper are motivated by a nascent stream of research in strategic networks that has begun to explore ways by which firms that are at the periphery of a network can form ties that make them more central (e.g. Ahuja, 2000;Rosenkopf et al, 2001; Rosenkopf and Padula, 2008; Ahuja, Polidoro and Mitchell, 2009), despite the powerful effects of structural homophily and preferential attachment that work toward reproducing the current structure of relationships (Barabasi and Albert, 1999; Gulati, 1995b; Walker, Kogut and Shan, 1997; Gulati and Gargiulo, 1999; Stuart, 1998). In contrast with prior studies that have explored whether and how relationally peripheral firms can move towards the center of the alliance network, I hypothesize *across* network structures about how *technologically* peripheral firms can gain *relational* advantages by their involvement in the standards committee, in order to offset their growing technological disadvantage.

Theoretical arguments

In Essay One, I discussed how a firm’s technological knowledge position amongst committee members indicates the extent to which other member firms have built upon the firm’s technology, and thus the extent to which the firm’s technology is regarded as foundational or fundamental within the committee. As I have argued, because technologically central firms will be able to exercise greater influence in shaping the standard, there is a greater likelihood that the standard’s rules will continue to build on such firms’ technologies. Thus, the standard will *technologically* favor firms with a more central position in the technological network of member firms, relative to firms with a more peripheral technological position. This is also consistent with the nature of technological change that follows the emergence of dominant design (Tushman and

Anderson, 1986). Firms that are central in the technological network of member firms in the committee are clearly foundational in the existing dominant design and their efforts will be to control the nature of change such that this design is preserved, refined and elaborated, while opposing those proposals that may result in major reconfigurations and potential competence erosion (Henderson and Clark, 1990; Kaplan and Tripsas, 2008).

But, why might such technological advantages or disadvantages translate into collaboration opportunities for member firms and into ties amongst specific pairs of firms? There are broadly two rationales for linking firms' technological network positions to their opportunities for tie formation in the alliance network. Firstly, even in a post-dominant design era, the direction of technological change may not be fully pre-determined. As the technical complexity of the underlying system increases with component and interface innovations, and as both core and peripheral firms are involved in shaping the nature of technological change, sociopolitical dynamics are likely to have a greater impact on the evolution of these communities (Tushman and Rosenkopf, 1992; cf. Tushman and Murmann, 1998). The focal empirical setting is a prototypical example of a complex technical system where the locus of innovation is distributed across the several different modules and subsystems that constitute the larger system (Baldwin and Clark, 2000). Second, economists studying standard-setting have discussed the idea of side-payments or concessions as mechanisms of compromise within voluntary standards-setting organizations (Simcoe, 2012). One potential such outcome of the sociopolitical dynamics and the divergence of interests within standards-setting committees could be a strategic collaboration agreement between the conflicted firms.

Keeping these rationales in mind, I first develop firm-level hypotheses that predict the likelihood of collaboration opportunities and then develop a dyad-level hypothesis that predicts the characteristics of pairs of firms that are likely to forge these alliances.

Technological position and relational advantages

With the emergence of the standard, the structure of the technological network linking the inventions of the participating member firms continues to evolve, as firms continue to build on each other's inventions (cf. Stuart and Podolny, 1996). These links reflect, in part, the degree of technological importance and influence a firm wields within the technical standards committee.

Firms that are central in this technological network will also stand to attract greater relational advantages than the peripheral firms. First, a firm's technological centrality amongst standards committee member firms is likely to attract potential partners who are looking to develop products on the standard and thus attracted to such firms to tap their technical capital. A high number of technological linkages (citations) to a particular firm's technological invention indicates that more firms are building on that invention and reflects the importance of a firm's invention relative to its peers on the standards committee. Thus, in part, it reveals the path of technological progress by identifying technologies that are foundational and stable. This may be a compelling signal for firms in technologically uncertain but path-dependent environments that need to make irreversible technological bets. Second, firms may be able reduce obsolescence risk by recombining knowledge from foundational technologies. However, while the technological network reveals stable technologies, and while the underlying patents disclose the technological design, they do not fully disclose the complexity of the underlying technology (cf. Fleming and Sorenson, 2004). As interdependence between technologies increases, recombination becomes more complex, and the technologies that develop on the stable core may decline in usefulness (Fleming and Sorenson, 2001). One reason for this is that patents don't include the tacit knowledge and idiosyncratic processes that transform the invention into a successful commercial product. The patenting firm may also choose to strategically maintain secrecy of critical portions of the technology. For firms that intend to build on these knowledge foundations, formal strategic alliances may allow for a more fine-grained, accurate and comprehensive knowledge transfer of this technological capital. Finally, by virtue of their increasing technological prominence, central firms are also in better bargaining positions to favorably negotiate the contractual terms of these potential collaborations (Stuart, 1998). Thus, I hypothesize:

> *Hypothesis 1: The higher (lower) a firm's technological network centrality amongst member firms, the higher (lower) the likelihood that it will form alliances with these firms*

Involvement in the committee and relational advantages

Prior research has established that standards-setting organizations are important venues for the fostering of new inter-organizational ties (Rosenkopf et al, 2001; Rosenkopf and Schleicher, 2008). However, firms may face substantial uncertainty about these collaborations before the standard is eventually set and agreed upon. With the standard still evolving, there may be significant technological uncertainty about the ultimate specification and direction of investment that firms need to make. Similarly, given that some firms who are members of the committee may not be in favor of the standard there may be additional uncertainty with regard to which firms might be trustworthy collaborative partners to build on the standard. A factor that may make firms more or less attractive as alliance partners is their extent of involvement in drafting the standard and supporting its emergence.

Internal involvement in a standards committee can be conceptualized at different levels. Firms have to make a decision with regard to how many engineers they should commit to attending standards-setting meetings. Firms also need to assess how much time and effort should be devoted in drafting technical contributions (proposals) for the standards committee. Finally, firms have to make strategic decisions on whether they should support or contest the emergence of the proposed standard.

The level of a firm's support for the standard reveals critical information not only about a firm's technological viewpoints but also about its commitment to the passage of the standard, and its inclination to collaborate with other firms to build products on the standard. These types of information about a firm's involvement are signals (Spence, 1973) that serve to reduce uncertainty about it as a potential alliance partner. As prior work has posited, uncertainty is an important factor that affects consideration of future alliance partners (Gulati, 1999). As uncertainty about a firm reduces, its attractiveness as a potential partner should increase. For instance, from these commitments, firms can infer whether other firms are able to advance a joint agenda based on collaborative technical principles or whether common interests are superseded by private organizational goals

(Rosenkopf et al, 2001). Similarly, involvement also signals the level of effort that firms are likely to exert in exploring and exploiting opportunities that arise from the standard (Lavie et al, 2007). For instance, firms that are do not contribute technical ideas or consistently vote against proceeding unconditionally with the standard on ballot measures, are less likely to dedicate resources to building products and technologies based on the standard. When a firm is technically involved in the committee and aligns with the consensus by voting to support the standard, it becomes increasingly attractive for potential partners who are looking to build on the standard, and thus will have a greater tendency to form alliances with peer firms. Thus, I hypothesize:

Hypothesis 2: The higher (lower) a firm's involvement in the standards committee, the higher (lower) the likelihood that it will form alliances with other member firms in the committee.

Give and take? Relational advantages of technologically peripheral firms' involvement

As both increasing technological centrality and increasing involvement in the standards committee positively affect a firm's alliance formation rate, the question arises as to which firms end up forming alliances with each other. A large body of work in social networks has argued that network ties are subject to the principle of preferential attachment (Barabasi and Albert, 1999) and structural or status homophily (Chung, Singh and Lee, 2000). In other words, a firm that is already central in an alliance network has a greater ability to attract partners by virtue of the advantages stemming from its network position (Gulati, 1995; Gulati, 1999). Ties may also be realized between structurally similar firms, either to reduce uncertainty or to mitigate appropriation hazards (Chung, Singh and Lee, 2000).

However, there is an emerging body of work that suggests that firms that are disadvantaged structurally may act strategically to offset their structural disadvantage. This work proposes that structural constraints can be overcome through firms' actions, causing the structure of the network to shift endogenously. For instance, Ahuja (2000b) shows that one mechanism for peripheral firms to form linkages is to achieve a radical technological breakthrough and disrupt the cycle of dominance by incumbent central players. Gulati and Gargiulo (1999) also suggest that the possession of a path-breaking invention or a new technology may lead to central firms' linkages with peripheral firms. Closer to my context, Rosenkopf et al (2001) find that alliance benefits from technical committee participation seem to be higher for firms that ex-ante have fewer alliances.

I propose that the asymmetry in the technological network of member firms in the committee incentivizes firms that are more central to reach out to firms that are more technologically disadvantaged (peripheral) in order to form a stable consensus. This is revealed in the rate of alliance ties between technologically central and technologically peripheral firms. Central firms have greater incentives to see that a consensus standard is adopted, and is done so expeditiously so that their technological prominence within the consortium can be transformed into industry-wide technology adoption (and consequently firm performance). However, central firms also need to build the legitimacy of the standard, by ensuring that participation in drafting the standard is broad and not confined to those central firms who would obviously benefit from it. As Garud, Jain and Kumaraswamy (2002) illustrate in the case of Sun Microsystems, firms that attempt to exercise overt control on the standard suffer from the 'sponsor's legitimacy trap' which ultimately deters the adoption of the standard. Sun spent three years attempting to establish Java as a standard that was de-jure but still remained under its control (West, 2003). This approached backfired and ultimately Sun was forced to relinquish control over the technology and adopt a hybrid open-standards approach (West, 2003). Similarly, the example of IBM 360 illustrates how IBM attempted to (unsuccessfully) control the evolution of its open architecture (Baldwin and Clark, 2000). Thus, there is a great disincentive for central firms to assert themselves in these committees and try to force a consensus by fiat.

Further, even from a technical systems design standpoint, a small number of modules in the system under consideration can lead to high levels of product complexity that mixing and matching different combinations of these modules entails, thus making it difficult for any one firm to control how the technology evolves (Baldwin and Clark, 2000). Thus, there may be a necessity even for central, advantaged firms to invest in wide-ranging relational capital to counter this uncertainty or possible loss of architectural control.

From a coalition formation standpoint, a two-thirds majority is sufficient in most technical committees to proceed with a proposal. However, in consensus-based committees, outstanding objections and comments are usually given due consideration (INCITS policies and procedures, 2012). The greater the number of objections, the greater the time taken to reach a consensus – as Simcoe (2012) shows, this is more often than not a problem that plagues voluntary standards setting organizations. From Essay One, these objections are more likely to come from the technologically peripheral firms who view the standard to be disadvantageous. Unresolved objections can lead to more adverse consequences for the proposed standard if disadvantaged firms decide to opt out of membership altogether or decide to focus their efforts in a competing alliance (as I discuss in Essay Three).

One important way that technologically central firms can mitigate such opposition from disadvantaged firms is by offering dyadic relational benefits. Prior research has explored how managers use alliances as a technique for behind-the-scenes coalition building, in particular when there is power asymmetry between different actors or stakeholders (e.g. Eisenhardt and Bourgeois, 1988). Similarly, in a case study of an inter-firm network, Elg and Johansson (1997) suggest that power asymmetry in an inter-firm network may result in central firms offering rewards to non-central firms to achieve network stability. These relational rewards with central firms may be very valuable for technologically peripheral firms. These firms are likely to be the smaller startup firms that need legitimacy to ensure capital inflow and liquidity. Prior research has also shown that variation in startups' ability to form alliances with prominent firms has significant consequences on both the likelihood of liquidity events and their innovative performance (Stuart, Hoang and Hybels, 1999; Baum et al, 2000; Gulati and Higgins, 2003).

In particular, in the face of increasing technological disadvantages from the evolving industry standard, the potential for forming alliances with technologically central players may act to offset these disadvantages. Beyond endorsement, as I posit in the first hypothesis, these linkages may also function as fine-grained knowledge transfer mechanisms that allow these peripheral firms to reconfigure their technologies to build on the foundational knowledge of the emerging standard that is localized within the central firms.

Probing this mechanism further, the question still remains whether any technologically peripheral firm will be the beneficiary of such a relationship or whether specific firms are likely to be targeted by the central players. If enhancing the legitimacy of the standard and accelerating its acceptance amongst member constituents is truly the underlying motive for the technologically central firms, then they are likely to be judicious in conferring these advantages so that these goals are achieved. Therefore, they are likely to seek out the specific firms that are not only increasingly technologically peripheral but also more disengaged in terms of their involvement in the workings of the committee. While the increasing asymmetry in the technological network positions indicates the extent of disparity in potential technological benefits, the increasing asymmetry in the involvement of these firms indicates which collaborations may provide the greatest legitimacy enhancements, should they form. Thus, I hypothesize:

> *Hypothesis 3: Among potential dyadic combinations of member firms, the greater the asymmetry between firms in a focal dyad in both the technological network position and in involvement in the technical standards committee, the greater the rate of alliance formation between them.*

Empirical Approach

Data Sources

All data sources were identical to those used in Essay One.

Measures

Dependent variables: Hypothesis 1 and Hypothesis 2 are about alliance formation at the firm level. I use a binary variable *Alliance with member firms* to measure this - this variable is set to 1 if a firm entered into any alliance with any one of the member firms in the standard, and 0 otherwise. Both the focal firm and at least one of the firm's alliance partners (if any) in that year, had to be on the membership roster for the same standards sub-committee in the same year for the variable to be set to 1. I also tested the robustness of this measure using a count of alliances instead of an indicator variable.

Hypothesis 3 is about alliance formation at the dyad level. I first created all the potential dyadic combinations by year based on standards sub-committee membership. In other words, if there were 'n' firms in a particular subcommittee in a particular year, then n*(n-1)/2 dyads were created for that sub-committee. Then I defined a variable corresponding to each of these dyads called *# of Alliances between firms in dyad*. This variable was calculated as the count of the number of ties between the two firms in the dyad in a particular year.

All alliances reported on Factiva (described in Essay One) including research and development, licensing and manufacturing agreements were considered for calculation of these dependent variables.

Independent variables

The independent variable to test Hypothesis 1 is *Tech. network centrality* and is measured identical to the way I describe the equivalent variable in Essay One. The independent variable to test Hypothesis 2 is *Involvement - Proposals submitted* and is measured as the yearly count of all technical proposals in the standards committee's electronic file database, where at least one of the authors is a representative of the focal firm. In order to facilitate this aggregation, I created a separate yearly mapping of firm representatives to firms, based on the standard's yearly membership roster.

To test Hypothesis 3, I needed to create an interaction variable of the asymmetry of any two member firms' technological network positions and the asymmetry of their involvement in the standards committees. This is a dyadic network measure, and as Ahuja, Polidoro and Mitchell (2009) discuss, merely creating a combined centrality score measure that is a product of each firm's centrality score does not accurately distinguish the asymmetric dyads from the symmetric dyads. This is because an asymmetric dyad - where one firm is central and the other firm is peripheral - may have a combined centrality score that is equivalent to a symmetric dyad where both firms have moderate centrality scores (e.g. 2x10 = 4x5). I therefore followed their approach and defined two indicator variables for each of the variables of interest- one for a low centrality dyad which is set to 1 if both firms in the dyad had a centrality score below the mean centrality score for that year, and the other for an asymmetry dyad which is set to 1 if one firm in the dyad had a centrality score greater than the mean and the other had a centrality score less than the mean.

Using this approach, I created two indicator variables to reflect the technology network position asymmetry in the dyad, namely *Low tech network centrality dyad*, and, *Asymmetry in tech network position dyad*. I then measured firms' involvement, and the asymmetry of this involvement in a dyad in two different ways. First, I used the count of times each firm voted in opposition to the standard and created two asymmetry indicator variables to reflect this at the dyad level - namely, *Low opposition to standard dyad* and *Asymmetry in opposition to standard* dyad. Second, I used a count of a firm's contributions in the standards committee and similarly created two asymmetry indicator variables to reflect the asymmetry at the dyad level - namely *Low contribution to standard dyad* and *Asymmetry in contribution to standard*. The contribution itself was measured in three alternate ways - (i) the total contributions, measured as the yearly count of *all* documents recorded under one of the firm's representatives names, (ii) the total technical contributions, measured as the difference of the total contributions and other non-technical documents such as notes, meeting minutes, schedule updates etc, and (iii) the total technical proposal contributions, measured as a count of only those documents that had proposal in the title or subject of the document.

Controls

Since alliance formation may be influenced by factors other than the hypothesized predictors, I used a number of controls to rule out these effects. I first discuss the controls for the models used to test Hypothesis 1 and 2, and then discuss the additional controls used to test Hypothesis 3.

Prior research on alliance formation has found significant effects for preferential attachment - in other words the more central a firm already is in the alliance network, the higher the likelihood that it will form additional alliances (Gulati, 1995b). I control for this with the measure *Alliance network centrality* which uses the same formulation as the equivalent measure discussed in Essay One. I also control for the relational prominence of a firm in the larger community of firms outside the standards body by including the measure *External alliances (non-members)* which is a count of alliances with non-member firms. I control for *Opposition to standard* which is measured as a count of ballot votes against proceeding unconditionally with the standard. I also control for the fact that levels of social interaction (that influences alliance formation) may be affected by the number of firm representatives attending meetings (e.g. Rosenkopf et al, 2001), by including the measure *# of Member engineers*. Similarly, I include a variable *Admin/Leadership tracker* that measures a count of administrative documents communicated to the committee by the firm's representatives (e.g. meeting minutes, agenda, announcement of ballot measures, results of ballot measures, call for patents letters etc.) to the committee, in order to control for leadership effects. I include a measure for *Tenure on standards committee* that may proxy for the level of knowledge about the standard arising purely from being on the committee for a longer duration. I include an indicator variable *Member in USB standard* to control for competitive effects from participating in an overlapping standards body. To control for a firm's technological resource base that may be a source of diversification and alliance opportunities, I include two measures - *Breadth of firm's technologies* that is a Herfindahl index of the primary technological classes of the firm's patents, and *Breadth of technologies building on firm's technology* that is a Herfindahl index of the primary technological classes of the patents of firms that cite the focal firm's patents. Finally, control for a host of firm financial measures that may all influence alliance formation opportunities, including - *Firm size (assets), Firm capital exp, Firm resources (cash), Firm leverage (long term debt), Firm performance (Sales)*. *Firm performance (ROA)* and *Size of firm's sector* (measured as the total cumulative assets of all publicly listed firms that operate in the same four digit SIC code as the firm). Logged versions of the firm financial variables were used in all the models.

For the models used to test Hypothesis 3, an equivalent set of controls was included with the difference being that there was a separate variable for each of the two firms in the dyad, for the same measure - for example, *Firm 1 Assets* and *Firm 2 Assets* were two variables (reflecting the firm size for each of the two firms)that were simultaneously included in these models. In addition, several dyad-level controls that have been known to predict alliance formation were included. Both *Alliance network low centrality dyad* and *Alliance network position asymmetry dyad* were included to control for the endogenous effects of the alliance network position on future alliance formation opportunities. *Prior alliances between Firm 1 and Firm 2*, which is a count of the prior strategic relationships between the two firms in the dyad, captures the effect of repeated ties and relational capital on future collaborations (Gulati, 1995b; Gulati and Gargiulo, 1999). *Product-market similarity for Firm 1 & 2* is an indicator variable to measure the similarity in the resource bases of the two firms in the dyad. It is set to 1 if the two firms in the dyad belonged to the same four digit SIC code.

Method

I model the data as an unbalanced panel as membership in the INCITS standards committees varies over the years. For Hypothesis 1 and 2, I use firm fixed-effects models to control for unobserved heterogeneity, but show equivalent results with random-effects models as well. By using firm-fixed effects models, I can control for unobserved firm characteristics to the extent that they are time-invariant. However, for Hypothesis 3, I was restricted to using random-effects models because a very large proportion of the dyads do not experience any alliances and they would drop out altogether from the fixed-effects models, thus reducing the sample by more than 90%. Most dyad level studies of alliance formation have followed a similar approach of using random-effects models (e.g. Rosenkopf et al, 2001; Gulati and Gargiulo, 1999).

I also lag all the independent variables and controls by one year to mitigate simultaneity and reverse-causality concerns. Since I postulated a causal relationship between a firm's network positions and its opposition to the standard in Essay One, the measures relating to technological and alliance network centrality are lagged by an additional year. In other words, the dependent variable is measured at time 't', the involvement variables are measured at time 't-1' and the network variables are measured at time 't-2'. For Hypothesis 1 and 2, as the dependent variable is a binary outcome, I model alliance formation using logistic regression models. I also show equivalent results with probit models and GLS regression models where the dependent variable is a log of the count of alliances.

Results

Table 7 shows the descriptive statistics of the sample used to test Hypothesis 1 and Hypothesis 2. The high correlations between the *Technological network centrality* measure and some of the control variables indicates that multicollinearity could be a concern. However, multicollinearity diagnostics revealed that the variance inflation factors were within acceptable limits. The bi-variate correlations between the dependent variable and the two independent variables are modest (0.55 with the *Technological network centrality* and 0.23 with the *Involvement* variable).

TABLE 7: Essay Two. Descriptive statistics and correlations for Hypotheses 1 and 2.

	Variable	Mean	S.D.	1	2	3	4	5	6	7	8
1	Alliance with member firms (Indicator variable)	0.4	0.49	1							
2	Tech. network centrality	0.44	0.29	0.55	1						
3	Involvement - Proposals submitted	0.41	1.28	0.23	0.09	1					
4	Alliance network centrality	0.81	1.41	0.3	0.44	0.05	1				
5	External alliances (non-members)	4.23	20.06	0.25	0.3	0.11	0.64	1			
	Variable	Mean	S.D.	1	2	3	4	5	6	7	8
6	Opposition to standard	0.57	1.27	0.19	0.05	0.35	0.09	0.12	1		
7	# of Member engineers	1.51	1.2	0.15	0.15	0.25	0.03	0.1	0.18	1	
8	Admin/Leadership	5.24	16.15	0.23	0.05	0.57	0.08	0.11	0.45	0.18	1
9	Tenure on standards committee	5.67	4.2	0.32	0.43	0.06	0.37	0.18	0.15	0.12	0.22
10	Member in USB standard	0.25	0.43	0.36	0.45	0.01	0.38	0.24	0.04	0.08	0.05
11	Breadth of firm's technologies (Herfindahl)	0.7	0.28	0.44	0.56	0.11	0.29	0.2	0.05	0.05	0.1
12	Breadth of technologies building on firm's tech. (classes)	90.5	85.25	0.49	0.85	0.07	0.41	0.34	0.03	0.17	0.03
13	Firm size (assets)	8.09	2.25	0.45	0.68	0.08	0.48	0.31	0.04	0.13	0.05
14	Firm capital exp	0.48	0.6	0.36	0.58	0.04	0.45	0.32	0.02	0.12	-0.03
15	Firm resources (cash)	0.69	0.76	0.44	0.63	0.08	0.6	0.37	0.06	0.13	0.04
16	Firm leverage (long term debt)	0.68	0.87	0.3	0.52	0.02	0.3	0.23	-0.01	0.11	-0.01
17	Firm performance (Sales)	11.61	20.39	0.38	0.57	0.1	0.6	0.49	0.08	0.16	0.07
18	Firm performance (ROA)	0	0.24	0.08	0.11	0.01	0.14	0.1	0.03	0.05	0.01
19	Size of firm's sector	10.78	1.38	0.35	0.38	0.07	0.3	0.21	0	-0.01	0.1

(Table continued)

	Variable	9	10	11	12	13	14	15	16	17	18	19
9	Tenure on standards committee	1										
10	Member in USB standard	0.6	1									
11	Breadth of firm's technologies	0.15	0.21	1								
12	Breadth of technologies building on firm's tech.	0.36	0.41	0.54	1							
13	Firm size (assets)	0.35	0.38	0.51	0.74	1						
14	Firm capital exp	0.27	0.32	0.41	0.74	0.79	1					
15	Firm resources (cash)	0.35	0.39	0.47	0.7	0.82	0.83	1				
16	Firm leverage (long term debt)	0.22	0.25	0.38	0.73	0.74	0.82	0.72	1			
17	Firm performance (Sales)	0.33	0.34	0.36	0.73	0.7	0.81	0.82	0.76	1		
18	Firm performance (ROA)	0.14	0.08	0.1	0.12	0.19	0.16	0.12	0.06	0.11	1	
19	Size of firm's sector	0.15	0.2	0.52	0.37	0.4	0.45	0.46	0.37	0.38	0.04	1

Table 8 shows the results of the firm fixed effects logistic regression models to test Hypothesis 1 and Hypothesis 2. Model 1 is the controls-only model and in Models 2, 3 and 4, I add the hypothesized variables of interest sequentially. Hypothesis 1 stated that the higher a firm's technological network centrality amongst member firms, the higher the likelihood that the firm will enter into alliances with these firms. The coefficient for the variable *Technological network centrality* is positive and highly significant ($p < 0.01$) in Model 2 and in Model 4, providing strong support for this hypothesis. A one standard deviation increase in this variable increases the likelihood of alliance formation by 29%.

Hypothesis 2 stated that higher involvement in the standards committee will be associated with a higher likelihood of alliance formation with firms in the committee. The coefficient for the variable *Involvement - Proposals submitted* is positive and significant ($p < 0.1$) in Model 3 and in Model 4, providing support for this hypothesis. A one standard deviation increase in this variable increases the likelihood of alliance formation by 73%.

Table 9 shows the results for alternate models used to test these hypotheses. Model 5 shows the results of a random-effects logistic regression model, Model 6 shows the results of a probit regression model and Model 7 shows the results of a GLS regression model with the dependent variable as the log-count of alliances for a firm. The results from these models are consistent with the earlier results using firm-fixed effects logistic regression models. Notably, the significance of the coefficient for *Involvement - Proposals submitted* increases in all these three models (from $p < 0.1$ to $p < 0.05$).

TABLE 8: Essay Two. Results for Hypothesis 1 and 2. Firm fixed-effects logistic regression models.

Dependent variable is 1 if firm enters into an alliance with a member firm and 0 otherwise.

MODELS VARIABLES	(1)	(2)	(3)	(4)
Tech. network centrality		8.0532***		8.1822***
		(2.4934)		(2.5291)
Involvement - Proposals submitted			0.3013*	0.3147*
			(0.1699)	(0.1764)
CONTROLS				
Opposition to standard	-0.0047	0.0053	-0.0185	-0.0159
	(0.1300)	(0.1347)	(0.1309)	(0.1343)
# of Member engineers	0.0959	0.0733	0.0668	0.0395
	(0.1415)	(0.1437)	(0.1417)	(0.1454)
Alliance network centrality	0.2770	0.3099	0.2542	0.2474
	(0.7400)	(0.7566)	(0.7380)	(0.7469)
# of External alliances (non-members)	0.3122***	0.3562***	0.3154***	0.3591***
	(0.1073)	(0.1127)	(0.1061)	(0.1112)
Admin/Leadership tracker	-0.0248**	-0.0153	-0.0363**	-0.0267*
	(0.0126)	(0.0116)	(0.0147)	(0.0141)
Member in USB standard	1.1023	1.0776	1.1045	1.0838
	(0.7043)	(0.7366)	(0.7087)	(0.7429)
Breadth of firm's technologies	-0.3603	-1.1027	0.1555	-0.6047
(Herfindahl index of patents/classes)	(2.0035)	(2.0682)	(2.0958)	(2.1411)
Breadth of technologies building on	0.0135	-0.0034	0.0107	-0.0076
firm's tech. (# of patent classes)	(0.0168)	(0.0182)	(0.0169)	(0.0185)
Firm size (assets)	0.3481	0.0864	0.3016	0.0226
	(0.3368)	(0.3511)	(0.3387)	(0.3527)
Firm capital exp	0.0395	0.5844	-0.1070	0.3836
	(1.1931)	(1.2014)	(1.1829)	(1.1937)
Firm resources (cash)	-1.0776	-1.4015	-1.1378	-1.4381*
	(0.8183)	(0.8521)	(0.8111)	(0.8456)
Firm leverage (long term debt)	0.5129	0.3974	0.4570	0.3855
	(0.7751)	(0.7953)	(0.7741)	(0.7930)
Firm performance (Sales)	0.0057	-0.0023	0.0007	-0.0071
	(0.0403)	(0.0411)	(0.0403)	(0.0411)
Firm performance (ROA)	-0.3592	-0.1357	-0.3291	-0.1202
	(0.9668)	(0.9822)	(0.9715)	(0.9810)
Size of firm's sector	-0.7932	-2.3540**	-0.6041	-2.1230**
	(0.7326)	(0.9295)	(0.7465)	(0.9356)
Observations	428	428	428	428
Firms	60	60	60	60
Log-likelihood	-125.3	-119.3	-123.7	-117.6
Chi-square	73.04	85.02	76.34	88.40

Standard errors in parentheses ***p<0.01, ** p<0.05, * p<0.1

TABLE 9: Essay Two. Results for Hypotheses 1 and 2. Alternate models.

MODELS VARIABLES	(5) Logit (RE)	(6) Probit (RE)	(7) Xtreg RE
Tech. network centrality	2.4199**	1.3096**	0.4920**
	(1.1849)	(0.6563)	(0.2209)
Involvement - Proposals submitted	0.2829**	0.1654**	0.0363**
	(0.1224)	(0.0701)	(0.0174)
Opposition to standard	0.1535	0.0907	0.0355**
	(0.1039)	(0.0596)	(0.0172)
# of Member engineers	0.0243	0.0184	0.0104
	(0.1014)	(0.0579)	(0.0185)
Alliance network centrality	2.8095***	1.5118***	0.1262***
	(0.6854)	(0.3661)	(0.0299)
External alliances (non-members)	0.1909***	0.1073***	0.0101***
	(0.0712)	(0.0400)	(0.0012)
Admin/Leadership tracker	-0.0149	-0.0076	0.0007
	(0.0094)	(0.0054)	(0.0016)
Year of Joining the Committee	-0.0450	-0.0246	0.0056
	(0.0631)	(0.0358)	(0.0130)
Member in USB standard	0.2006	0.1033	0.0167
	(0.4660)	(0.2645)	(0.0897)
Breadth of firm's technologies	0.4952	0.3638	0.5164**
	(1.0622)	(0.5997)	(0.2103)
Breadth of technologies building on	-0.0021	-0.0011	0.0007
firm's tech. (classes)	(0.0048)	(0.0027)	(0.0009)
Firm size (assets)	0.0052	0.0105	0.0841**
	(0.1761)	(0.0996)	(0.0360)
Firm capital exp	0.4858	0.2280	0.0833
	(0.7173)	(0.3936)	(0.1111)
Firm resources (cash)	0.4404	0.2770	0.2751***
	(0.4942)	(0.2739)	(0.0772)
Firm leverage (long term debt)	0.1929	0.0916	-0.2141***
	(0.4084)	(0.2301)	(0.0636)
Firm performance (Sales)	-0.0068	-0.0032	-0.0007
	(0.0215)	(0.0119)	(0.0030)
Firm performance (ROA)	0.9161	0.5345	0.1028
	(0.7160)	(0.4070)	(0.1209)
Size of firm's sector	0.4046**	0.2276**	0.0130
	(0.1973)	(0.1114)	(0.0417)
Constant	-7.6325***	-4.3959***	-1.0962**
	(2.5306)	(1.4291)	(0.5285)
Observations	858	858	858
Firms	156	156	156
Log likelihood	-298.5	-298.8	NA
R-Square (Overall)	NA	NA	0.67

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 10 shows the descriptive statistics of the variables to test Hypothesis 3. The dependent variable *# of Alliances between firms in dyad* has a mean of 0.03 indicating that very few dyads had any alliances between their constituent firms. Table 11 shows the correlations between the variables. The high correlations for the paired indicator variables measuring dyadic asymmetry are expected by the nature of their construction.

TABLE 10: Essay Two. Descriptive statistics for Hypothesis 3.

	Variables	Mean	S.D.
1	# of Alliances between firms in dyad	0.03	0.33
2	Tech. network position asymmetry dyad	0.48	0.5
3	Asymmetry in opposition to standard	0.36	0.48
4	Asymmetry in contribution to standard	0.21	0.41
5	Low tech network centrality dyad	0.19	0.39
6	Low opposition to standard dyad	0.56	0.5
7	Low contribution to standard dyad	0.78	0.42
8	Alliance network low centrality dyad	0.11	0.31
9	Alliance network position asymmetry dyad	0.41	0.49
10	Prior alliances between Firm 1 and Firm 2	0.07	0.25
11	Product-market similarity for Firm 1 & 2	0.16	0.37
12	Documents by Firm 1	10.54	27.23
13	Documents by Firm 2	6.63	20.13
14	Firm 1 Assets	7.98	2.29
15	Firm 2 Assets	7.87	2.28
16	Firm 1 R&D	5.46	2.1
17	Firm 2 R&D	5.43	2.06
18	Firm 1 Capital Exp	5	2.31
19	Firm 2 Capital Exp	4.96	2.34
20	Firm 1 Resources in Cash	5.73	2.3
21	Firm 2 Resources in Cash	5.72	2.15
22	Firm 1 Performance (income)	571.94	3205
23	Firm 2 Performance (income)	467.49	3228.78
24	Firm 1 Leverage (debt)	4.79	3.3
25	Firm 2 Leverage (debt)	4.84	3.24
26	Firm 1 Mkt Share	1.16	0.21
27	Firm 2 Mkt Share	1.13	0.19
28	Firm 1 Patent stock (5yr)	960.53	2160.4
29	Firm 2 Patent stock (5yr)	879.9	1933.95
30	Citations to firm 1's patents (5yr)	9304.3	22811.9
31	Citations to firm 2's patents (5yr)	7724.2	19198.6

TABLE 11: Essay Two. Correlations for Hypothesis 3.

#	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	-0.05	1									
3	0.02	0	1								
4	0.06	0	0.3	1							
5	-0.04	-0.46	-0.03	-0.03	1						
6	-0.06	0	-0.86	-0.38	0.04	1					
7	-0.09	0	-0.29	-0.96	0.03	0.4	1				
8	0	-0.01	0.04	0.06	-0.02	-0.06	-0.07	1			
9	0	-0.01	0.02	0.04	-0.04	-0.04	-0.04	-0.29	1		
10	0.29	-0.1	0.06	0.12	-0.09	-0.13	-0.16	0.12	0.07	1	
11	-0.02	0	-0.05	-0.07	-0.01	0.06	0.08	-0.05	-0.18	-0.03	1
12	0.1	0	0.21	0.56	0	-0.31	-0.62	0.07	0.04	0.16	-0.06
13	0.07	0	0.15	0.43	-0.03	-0.25	-0.51	0.09	0.05	0.16	-0.05
14	0.11	-0.06	0.06	0.07	-0.24	-0.09	-0.08	0.01	0.06	0.21	-0.06
15	0.11	-0.07	0.05	0.06	-0.23	-0.07	-0.07	0.06	0.08	0.22	-0.08
16	0.11	-0.07	0.09	0.1	-0.27	-0.12	-0.11	0.05	0.08	0.23	-0.03
17	0.12	-0.07	0.06	0.08	-0.25	-0.09	-0.1	0.09	0.09	0.24	-0.06
18	0.1	-0.06	0.06	0.06	-0.25	-0.07	-0.06	-0.02	0.04	0.18	-0.06
19	0.11	-0.07	0.04	0.05	-0.23	-0.06	-0.06	0.02	0.05	0.2	-0.08
20	0.11	-0.06	0.08	0.1	-0.26	-0.11	-0.11	0.05	0.07	0.23	-0.03
21	0.11	-0.07	0.06	0.07	-0.23	-0.08	-0.08	0.08	0.08	0.24	-0.06
22	0.1	-0.02	0.04	0.08	-0.09	-0.07	-0.09	-0.07	-0.02	0.13	-0.02
23	0.12	-0.01	0.01	0.05	-0.07	-0.04	-0.06	-0.04	-0.01	0.12	-0.03
24	0.05	-0.04	0.02	0	-0.17	-0.01	0.01	0	0.04	0.12	-0.07
25	0.04	-0.05	0.02	0.01	-0.17	-0.01	-0.01	0.03	0.07	0.13	-0.09
26	0.09	-0.03	0.06	0.08	-0.15	-0.08	-0.08	-0.03	0.03	0.16	-0.15
27	0.07	-0.04	0.01	0.04	-0.15	-0.01	-0.05	-0.01	0.03	0.14	-0.1
28	0.18	-0.06	0.09	0.18	-0.22	-0.12	-0.2	-0.02	0.02	0.21	-0.09
29	0.19	-0.07	0.05	0.11	-0.23	-0.08	-0.14	0.02	0.05	0.25	-0.1
30	0.19	-0.06	0.09	0.15	-0.21	-0.11	-0.16	-0.03	0.01	0.21	-0.09
31	0.18	-0.06	0.06	0.11	-0.21	-0.09	-0.13	0.02	0.04	0.25	-0.09

#	12	13	14	15	16	17	18	19	20	21	22
12	1										
13	0.03	1									
14	0.1	0	1								
15	0.03	0.11	0.01	1							
16	0.15	0	0.94	0.01	1						
17	0.03	0.14	0.02	0.94	0.01	1					
18	0.07	-0.02	0.95	-0.01	0.91	0	1				
19	0.01	0.08	0	0.95	-0.01	0.92	0	1			
20	0.15	0	0.91	0.02	0.92	0.03	0.85	-0.01	1		
21	0.03	0.13	0.02	0.93	0.02	0.92	0	0.88	0.04	1	

#	12	13	14	15	16	17	18	19	20	21	22
22	0.08	0	0.23	0.02	0.22	0.02	0.35	0.01	0.21	0.02	1
23	0.01	0.08	0.01	0.2	0	0.19	-0.01	0.31	0.01	0.18	0.04
#	12	13	14	15	16	17	18	19	20	21	22
24	0	-0.01	0.71	-0.01	0.61	0	0.68	-0.01	0.59	0	0.11
25	0.01	0.05	0	0.78	0	0.7	-0.01	0.76	0	0.68	0
26	0.08	0.02	0.65	0.01	0.54	0.02	0.62	0	0.54	0.02	0.23
27	0.01	0.08	-0.01	0.58	-0.01	0.5	-0.02	0.56	-0.01	0.5	0
28	0.25	-0.02	0.49	-0.01	0.5	-0.01	0.49	-0.02	0.45	-0.01	0.3
29	0.01	0.25	0.01	0.53	0	0.54	0	0.54	0.01	0.5	0
30	0.21	-0.02	0.48	-0.01	0.47	0	0.48	-0.01	0.45	-0.01	0.27
31	0.02	0.23	0.01	0.49	0	0.5	-0.01	0.48	0.01	0.46	-0.01

#	23	24	25	26	27	28	29	30	31
23	1								
24	0	1							
25	0.09	-0.01	1						
26	0	0.45	0	1					
27	0.17	-0.02	0.47	0	1				
28	-0.01	0.39	-0.02	0.31	-0.02	1			
29	0.25	-0.01	0.44	0.01	0.36	0.01	1		
30	0	0.41	-0.02	0.37	-0.02	0.89	0.01	1	
31	0.23	-0.01	0.41	0.01	0.37	0	0.89	0.01	1

Hypothesis 3 posited that among potential dyadic combinations of member firms, the greater the asymmetry between firms in a focal dyad in both the technological network position and in involvement in the technical standards committee, the greater the rate of alliance formation between them. I predict a positive coefficient for the interaction between the dyadic asymmetry in the technological network and the dyadic asymmetry in the involvement. Tables 12 through 17 show the results of the panel Poisson random-effects regression models for testing hypothesis 3. In Table 12, involvement is operationalized as voting opposition, while simultaneously controlling for the number of documents contributed as an alternate measure of involvement. The coefficient for *Asymmetry in opposition to standard X Tech. network position asymmetry* is positive and significant ($p < 0.05$) thus providing support for this hypothesis.

TABLE 12: Essay Two. Results for Hypothesis 3. Involvement as opposition, controlling for total contributions.

Dependent variable is Number of alliances between firm i and firm j in a year. Random effects panel data Poisson regression models.

MODELS VARIABLES	(8)	(9)	(10)	(11)
Tech. network position asymmetry		-0.2018**	-0.2138**	-0.2419***
dyad		(0.0900)	(0.0899)	(0.0912)
Asymmetry in opposition to standard			-0.2043***	-0.1382*
			(0.0657)	(0.0732)
Asymmetry in opposition to standard				0.2506**
X Tech. network position asymmetry				(0.1222)
CONTROLS				
Tech. network low centrality dyad	-0.0695	-0.2464	-0.2574	-0.2613
	(0.1545)	(0.1737)	(0.1737)	(0.1738)
Low opposition to standard dyad	-0.1536**	-0.1563**	-0.3199***	-0.3163***
	(0.0657)	(0.0656)	(0.0836)	(0.0838)
Alliance network low centrality dyad	0.0542	0.0454	0.0499	0.0520
	(0.1026)	(0.1026)	(0.1024)	(0.1024)
Alliance network position	-0.1249*	-0.1226*	-0.1210*	-0.1172*
asymmetric dyad	(0.0681)	(0.0681)	(0.0680)	(0.0680)
Prior alliances between	0.5825***	0.5588***	0.5525***	0.5509***
Firm 1 & 2	(0.1040)	(0.1043)	(0.1041)	(0.1041)
Product-market similarity	0.4245***	0.4212***	0.4198***	0.4190***
Firm 1 & 2	(0.1390)	(0.1390)	(0.1386)	(0.1387)
Documents by Firm 1	0.0057***	0.0060***	0.0058***	0.0058***
	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Documents by Firm 2	0.0025**	0.0026**	0.0023**	0.0024**
	(0.0010)	(0.0010)	(0.0010)	(0.0010)
Firm 1 Assets	0.2447***	0.2474***	0.2489***	0.2486***
	(0.0903)	(0.0902)	(0.0902)	(0.0903)
Firm 2 Assets	-0.1398	-0.1298	-0.1299	-0.1310
	(0.0914)	(0.0917)	(0.0917)	(0.0917)
Firm 1 R&D	0.2471***	0.2409***	0.2340***	0.2346***
	(0.0739)	(0.0739)	(0.0739)	(0.0739)
Firm 2 R&D	0.2203**	0.2000**	0.1922**	0.1916**
	(0.0900)	(0.0905)	(0.0905)	(0.0906)
Firm 1 Capital Exp	0.0531	0.0537	0.0562	0.0552
	(0.0497)	(0.0497)	(0.0496)	(0.0497)
Firm 2 Capital Exp	0.2729***	0.2714***	0.2679***	0.2665***
	(0.0516)	(0.0518)	(0.0518)	(0.0518)
Firm 1 Resources in Cash	-0.1452***	-0.1581***	-0.1540***	-0.1547***
	(0.0334)	(0.0339)	(0.0339)	(0.0340)
Firm 2 Resources in Cash	0.0298	0.0283	0.0374	0.0417
	(0.0495)	(0.0496)	(0.0499)	(0.0499)
Firm 1 Performance (income)	0.0000***	0.0000***	0.0000***	0.0000***

(Table continued) VARIABLES MODELS	(8)	(9)	(10)	(11)
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Performance (income)	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 1 Leverage (debt)	-0.1498***	-0.1507***	-0.1496***	-0.1499***
	(0.0138)	(0.0138)	(0.0138)	(0.0138)
Firm 2 Leverage (debt)	-0.1355***	-0.1378***	-0.1344***	-0.1344***
	(0.0155)	(0.0155)	(0.0155)	(0.0155)
Firm 1 Mkt Share	-0.7170***	-0.7486***	-0.7910***	-0.8001***
	(0.2510)	(0.2514)	(0.2512)	(0.2515)
Firm 2 Mkt Share	-0.4181	-0.4517*	-0.4483*	-0.4372*
	(0.2584)	(0.2589)	(0.2579)	(0.2580)
Firm 1 Patent stock (5yr)	0.0000	0.0000	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Patent stock (5yr)	0.0002***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 1's patents (5yr)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 2's patents (5yr)	-0.0000**	-0.0000**	-0.0000**	-0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant	-5.7702***	-5.4055***	-5.2084***	-5.2324***
	(0.4544)	(0.4815)	(0.4848)	(0.4852)
Observations	20807	20807	20807	20807
Number of dyads	5678	5678	5678	5678
Log likelihood	-4490	-4487	-4483	-4481
Chi-square	1374	1379	1394	1393

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

It is also worth noting that the coefficients for the base variables *Tech. network position asymmetry dyad* and *Asymmetry in opposition to standard* are negative and significant - although I did not theorize on the base variables, this shows that there are fewer alliances between firms that either had divergent technological network positions or divergent opinions about supporting the standard . In Table 13, involvement is operationalized as the number of documents contributed in the standard by the firm's representatives. The coefficient for *Asymmetry in contrib. to standard X Tech. network position asymmetry* is positive and significant ($p < 0.05$) thus providing additional support for this hypothesis using an alternative formulation for involvement.

TABLE 13: Essay Two. Results for Hypothesis 3. Involvement as total contribution, controlling for opposition.

Dependent variable is Number of alliances between firm i and firm j in a year. Panel Poisson regression models with random effects.

MODELS VARIABLES	(12)	(13)	(14)	(15)
Tech. network position asymmetry dyad		-0.1559* (0.0902)	-0.1790** (0.0898)	-0.2553*** (0.0963)
Asymmetry in contribution (all docs.) to standard			-0.4641*** (0.0894)	-0.3893*** (0.0953)
Asymmetry in contrib. to standard X Tech. network position asymmetry				0.3068** (0.1319)
CONTROLS				
Tech. network low centrality dyad	-0.0204 (0.1549)	-0.1566 (0.1740)	-0.1837 (0.1740)	-0.1966 (0.1741)
Low contribution dyad	-0.4712*** (0.0752)	-0.4806*** (0.0754)	-0.9087*** (0.1111)	-0.8943*** (0.1118)
Alliance network low centrality dyad	0.0765 (0.1034)	0.0707 (0.1034)	0.0721 (0.1032)	0.0731 (0.1033)
Alliance network position asymmetric dyad	-0.1017 (0.0685)	-0.0996 (0.0684)	-0.0936 (0.0683)	-0.0876 (0.0685)
Prior alliances between Firm 1 & 2	0.5516*** (0.1044)	0.5335*** (0.1048)	0.5104*** (0.1041)	0.5014*** (0.1044)
Product-market similarity Firm 1 & 2	0.4264*** (0.1419)	0.4232*** (0.1419)	0.4287*** (0.1402)	0.4229*** (0.1407)
Opposition to standard Firm 1	0.0497*** (0.0146)	0.0515*** (0.0146)	0.0413*** (0.0148)	0.0408*** (0.0147)
Opposition to standard Firm 2	0.0007 (0.0180)	0.0013 (0.0180)	-0.0072 (0.0183)	-0.0064 (0.0183)
Firm 1 Assets	0.2113** (0.0914)	0.2118** (0.0913)	0.2341** (0.0912)	0.2345** (0.0914)
Firm 2 Assets	-0.1497 (0.0926)	-0.1419 (0.0928)	-0.1425 (0.0925)	-0.1377 (0.0927)
Firm 1 R&D	0.2726*** (0.0751)	0.2688*** (0.0751)	0.2724*** (0.0748)	0.2720*** (0.0750)
Firm 2 R&D	0.2197** (0.0913)	0.2040** (0.0918)	0.2139** (0.0915)	0.2115** (0.0917)
Firm 1 Capital Exp	0.0447 (0.0505)	0.0450 (0.0505)	0.0262 (0.0503)	0.0260 (0.0504)
Firm 2 Capital Exp	0.2823*** (0.0522)	0.2817*** (0.0523)	0.2678*** (0.0523)	0.2636*** (0.0524)
Firm 1 Resources in Cash	-0.1265*** (0.0336)	-0.1355*** (0.0340)	-0.1398*** (0.0339)	-0.1397*** (0.0341)
Firm 2 Resources in Cash	0.0335 (0.0499)	0.0319 (0.0500)	0.0385 (0.0499)	0.0392 (0.0500)
Firm 1 Performance (income)	0.0000*** (0.0000)	0.0000*** (0.0000)	0.0000*** (0.0000)	0.0000*** (0.0000)

(Table continued) VARIABLES	MODELS	(12)	(13)	(14)	(15)
Firm 2 Performance (income)		0.0001***	0.0001***	0.0001***	0.0001***
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 1 Leverage (debt)		-0.1566***	-0.1577***	-0.1534***	-0.1543***
		(0.0139)	(0.0139)	(0.0139)	(0.0139)
Firm 2 Leverage (debt)		-0.1358***	-0.1376***	-0.1339***	-0.1332***
		(0.0155)	(0.0156)	(0.0155)	(0.0155)
Firm 1 Mkt Share		-0.5956**	-0.6163**	-0.6251**	-0.6280**
		(0.2532)	(0.2536)	(0.2518)	(0.2524)
Firm 2 Mkt Share		-0.3876	-0.4138	-0.4049	-0.3989
		(0.2618)	(0.2623)	(0.2599)	(0.2604)
Firm 1 Patent stock (5yr)		0.0000**	0.0000*	0.0000	0.0000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Patent stock (5yr)		0.0002***	0.0002***	0.0001***	0.0001***
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 1's patents (5yr)		0.0000***	0.0000***	0.0000***	0.0000***
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 2's patents (5yr)		-0.0000*	-0.0000*	-0.0000	-0.0000*
		(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant		-5.5717***	-5.2831***	-4.9766***	-4.9910***
		(0.4576)	(0.4862)	(0.4867)	(0.4879)
Observations		20807	20807	20807	20807
Number of dyads		5678	5678	5678	5678
Log likelihood		-4497	-4495	-4482	-4479
Chi-square		1315	1317	1354	1349

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

In the above formulation as well, significant effects are observed for the base variables thus making the opposing significant effect for the hypothesized interaction variable even more compelling. Tables 14-17 provide results from equivalent regression models where I studied the effect of using alternate formulations for firms' contributions to the standard - as number of technical proposals (in Table 14 as a control and Table 15 as a predictor) and as number of technical contributions (in Table 16 as a control and Table 17 as a predictor). All these models provide consistent and robust results supporting Hypothesis 3.

TABLE 14: Essay Two. Results for Hypothesis 3. Involvement as opposition, controlling for proposals.

Dependent variable is Number of alliances between firm i and firm j in a year. Panel Poisson regression models with random effects.

MODELS VARIABLES	(16)	(17)	(18)	(19)
Tech. network position asymmetry dyad		-0.1010 (0.0901)	-0.1155 (0.0899)	-0.1382 (0.0911)
Asymmetry in opposition to standard			-0.2107*** (0.0656)	-0.1559** (0.0732)
Asymmetry in opposition to standard X Tech. network position asymmetry				0.2078* (0.1224)
CONTROLS				
Tech. network low centrality dyad	0.0314 (0.1542)	-0.0559 (0.1728)	-0.0730 (0.1726)	-0.0757 (0.1727)
Low opposition to standard dyad	-0.2115*** (0.0645)	-0.2147*** (0.0645)	-0.3819*** (0.0824)	-0.3796*** (0.0826)
Alliance network low centrality dyad	0.1149 (0.1042)	0.1111 (0.1042)	0.1121 (0.1039)	0.1134 (0.1040)
Alliance network position asymmetric dyad	-0.0802 (0.0687)	-0.0785 (0.0687)	-0.0797 (0.0685)	-0.0766 (0.0686)
Prior alliances between Firm 1 & 2	0.5662*** (0.1044)	0.5547*** (0.1048)	0.5517*** (0.1046)	0.5508*** (0.1046)
Product-market similarity Firm 1 & 2	0.4434*** (0.1425)	0.4414*** (0.1425)	0.4382*** (0.1418)	0.4374*** (0.1419)
Proposals authored by Firm 1	0.0656*** (0.0134)	0.0660*** (0.0134)	0.0626*** (0.0134)	0.0619*** (0.0134)
Proposals by Firm 2	0.0309** (0.0140)	0.0306** (0.0140)	0.0277** (0.0140)	0.0274* (0.0140)
Firm 1 Assets	0.2345*** (0.0902)	0.2349*** (0.0902)	0.2380*** (0.0902)	0.2372*** (0.0902)
Firm 2 Assets	-0.1357 (0.0928)	-0.1303 (0.0931)	-0.1308 (0.0929)	-0.1315 (0.0929)
Firm 1 R&D	0.2541*** (0.0747)	0.2515*** (0.0747)	0.2440*** (0.0746)	0.2450*** (0.0746)
Firm 2 R&D	0.2098** (0.0911)	0.1991** (0.0917)	0.1901** (0.0915)	0.1893** (0.0916)
Firm 1 Capital Exp	0.0187 (0.0505)	0.0188 (0.0505)	0.0222 (0.0504)	0.0213 (0.0504)
Firm 2 Capital Exp	0.2647*** (0.0523)	0.2641*** (0.0524)	0.2616*** (0.0524)	0.2604*** (0.0524)
Firm 1 Resources in Cash	-0.1230*** (0.0336)	-0.1289*** (0.0340)	-0.1259*** (0.0340)	-0.1263*** (0.0341)
Firm 2 Resources in Cash	0.0449 (0.0499)	0.0441 (0.0500)	0.0532 (0.0502)	0.0566 (0.0502)

(Table continued)

MODELS VARIABLES	(16)	(17)	(18)	(19)
Firm 1 Performance (income)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Performance (income)	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 1 Leverage (debt)	-0.1584***	-0.1591***	-0.1577***	-0.1579***
	(0.0140)	(0.0140)	(0.0140)	(0.0140)
Firm 2 Leverage (debt)	-0.1379***	-0.1391***	-0.1354***	-0.1353***
	(0.0157)	(0.0157)	(0.0157)	(0.0157)
Firm 1 Mkt Share	-0.5042**	-0.5151**	-0.5751**	-0.5824**
	(0.2525)	(0.2528)	(0.2526)	(0.2529)
Firm 2 Mkt Share	-0.3640	-0.3814	-0.3844	-0.3749
	(0.2621)	(0.2627)	(0.2613)	(0.2615)
Firm 1 Patent stock (5yr)	0.0000*	0.0000*	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Patent stock (5yr)	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 1's patents (5yr)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 2's patents (5yr)	-0.0000	-0.0000	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant	-5.9566***	-5.7726***	-5.5453***	-5.5614***
	(0.4611)	(0.4888)	(0.4924)	(0.4927)
Observations	20807	20807	20807	20807
Number of dyads	5678	5678	5678	5678
Log likelihood	-4506	-4505	-4500	-4498
Chi-square	1296	1297	1316	1314

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

TABLE 15: Essay Two. Results for Hypothesis 3. Involvement as proposals, controlling for opposition.

Dependent variable is Number of alliances between firm i and firm j in a year. Panel Poisson regression models with random effects.

MODELS VARIABLES	(20)	(21)	(22)	(23)
Tech. network position asymmetry dyad		-0.1322 (0.0903)	-0.1344 (0.0903)	-0.2177** (0.0950)
Asymmetry in contribution (proposals) to standard			-0.1518* (0.0834)	-0.0452 (0.0905)
Asymmetry in contrib. to standard X Tech. network position asymmetry				0.3783*** (0.1229)
CONTROLS				
Tech. network low centrality dyad	-0.0326 (0.1546)	-0.1481 (0.1737)	-0.1560 (0.1738)	-0.1735 (0.1739)
Low contribution dyad	-0.1770*** (0.0610)	-0.1827*** (0.0612)	-0.3157*** (0.0951)	-0.2946*** (0.0956)
Alliance network low centrality dyad	0.0687 (0.1036)	0.0643 (0.1036)	0.0684 (0.1035)	0.0707 (0.1035)
Alliance network position asymmetric dyad	-0.0999 (0.0686)	-0.0977 (0.0686)	-0.0959 (0.0686)	-0.0893 (0.0686)
Prior alliances between Firm 1 & 2	0.5716*** (0.1053)	0.5563*** (0.1057)	0.5469*** (0.1058)	0.5456*** (0.1057)
Product-market similarity Firm 1 & 2	0.4327*** (0.1420)	0.4302*** (0.1420)	0.4283*** (0.1416)	0.4309*** (0.1417)
Opposition to standard Firm 1	0.0636*** (0.0144)	0.0653*** (0.0145)	0.0661*** (0.0145)	0.0652*** (0.0145)
Opposition to standard Firm 2	0.0144 (0.0177)	0.0152 (0.0177)	0.0154 (0.0177)	0.0137 (0.0178)
Firm 1 Assets	0.2065** (0.0921)	0.2073** (0.0921)	0.2241** (0.0925)	0.2319** (0.0927)
Firm 2 Assets	-0.1437 (0.0928)	-0.1369 (0.0931)	-0.1328 (0.0930)	-0.1317 (0.0932)
Firm 1 R&D	0.2636*** (0.0752)	0.2600*** (0.0752)	0.2492*** (0.0753)	0.2377*** (0.0752)
Firm 2 R&D	0.2128** (0.0911)	0.1994** (0.0916)	0.2009** (0.0915)	0.2010** (0.0915)
Firm 1 Capital Exp	0.0481 (0.0510)	0.0483 (0.0510)	0.0424 (0.0510)	0.0473 (0.0511)
Firm 2 Capital Exp	0.2862*** (0.0524)	0.2858*** (0.0525)	0.2800*** (0.0526)	0.2728*** (0.0527)

(Table continued)

VARIABLES / MODELS	(20)	(21)	(22)	(23)
Firm 1 Resources in Cash	-0.1242***	-0.1319***	-0.1324***	-0.1354***
	(0.0338)	(0.0342)	(0.0342)	(0.0342)
Firm 2 Resources in Cash	0.0261	0.0245	0.0269	0.0288
	(0.0499)	(0.0499)	(0.0499)	(0.0501)
Firm 1 Performance (income)	0.0000**	0.0000**	0.0000***	0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Performance (income)	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 1 Leverage (debt)	-0.1612***	-0.1621***	-0.1605***	-0.1623***
	(0.0139)	(0.0140)	(0.0140)	(0.0140)
Firm 2 Leverage (debt)	-0.1420***	-0.1437***	-0.1437***	-0.1419***
	(0.0157)	(0.0157)	(0.0157)	(0.0157)
Firm 1 Mkt Share	-0.5693**	-0.5861**	-0.5944**	-0.5987**
	(0.2544)	(0.2547)	(0.2543)	(0.2544)
Firm 2 Mkt Share	-0.3391	-0.3606	-0.3750	-0.3682
	(0.2616)	(0.2621)	(0.2617)	(0.2619)
Firm 1 Patent stock (5yr)	0.0001**	0.0000**	0.0000**	0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Patent stock (5yr)	0.0002***	0.0002***	0.0002***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 1's patents (5yr)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 2's patents (5yr)	-0.0000*	-0.0000*	-0.0000*	-0.0000*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant	-5.7308***	-5.4893***	-5.4051***	-5.4158***
	(0.4574)	(0.4855)	(0.4874)	(0.4879)
Observations	20807	20807	20807	20807
Number of dyads	5678	5678	5678	5678
Log likelihood	-4512	-4511	-4509	-4505
Chi-square	1284	1286	1292	1296

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

TABLE 16: Essay Two. Results for Hypothesis 3. Involvement as opposition, controlling for technical documents.

Dependent variable is Number of alliances between firm i and firm j in a year. Panel Poisson regression models with random effects.

MODELS VARIABLES	(24)	(25)	(26)	(27)
Tech. network position asymmetry dyad		-0.1255	-0.1418	-0.1684*
		(0.0905)	(0.0903)	(0.0915)
Asymmetry in opposition to standard			-0.2388***	-0.1754**
			(0.0656)	(0.0732)
Asymmetry in opposition to standard X				0.2390*
Tech. network position asymmetry				(0.1223)
CONTROLS				
Tech. network low centrality dyad	-0.0163	-0.1267	-0.1433	-0.1473
	(0.1540)	(0.1735)	(0.1733)	(0.1733)
Low opposition to standard dyad	-0.2290***	-0.2313***	-0.4199***	-0.4157***
	(0.0650)	(0.0650)	(0.0825)	(0.0827)
Alliance network low centrality dyad	0.0543	0.0489	0.0536	0.0554
	(0.1035)	(0.1035)	(0.1032)	(0.1033)
Alliance network position asymmetric	-0.1138*	-0.1125	-0.1113	-0.1078
dyad	(0.0686)	(0.0686)	(0.0684)	(0.0685)
Prior alliances between Firm 1 & 2	0.5919***	0.5784***	0.5740***	0.5730***
	(0.1052)	(0.1055)	(0.1052)	(0.1052)
Product-market similarity Firm 1 & 2	0.4269***	0.4241***	0.4217***	0.4210***
	(0.1421)	(0.1421)	(0.1413)	(0.1414)
Tech. Documents by Firm 1	0.0039**	0.0042**	0.0042**	0.0043**
	(0.0016)	(0.0017)	(0.0017)	(0.0017)
Tech. Documents by Firm 2	0.0018	0.0018	0.0012	0.0012
	(0.0020)	(0.0020)	(0.0020)	(0.0020)
Firm 1 Assets	0.2039**	0.2043**	0.2087**	0.2085**
	(0.0909)	(0.0909)	(0.0908)	(0.0909)
Firm 2 Assets	-0.1248	-0.1183	-0.1193	-0.1204
	(0.0923)	(0.0926)	(0.0924)	(0.0925)
Firm 1 R&D	0.2818***	0.2788***	0.2683***	0.2690***
	(0.0749)	(0.0749)	(0.0748)	(0.0748)
Firm 2 R&D	0.1957**	0.1832**	0.1730*	0.1725*
	(0.0908)	(0.0913)	(0.0911)	(0.0912)
Firm 1 Capital Exp	0.0443	0.0452	0.0485	0.0475
	(0.0506)	(0.0505)	(0.0504)	(0.0505)
Firm 2 Capital Exp	0.2724***	0.2714***	0.2669***	0.2653***
	(0.0520)	(0.0522)	(0.0521)	(0.0522)
Firm 1 Resources in Cash	-0.1334***	-0.1413***	-0.1374***	-0.1382***
	(0.0335)	(0.0340)	(0.0340)	(0.0341)
Firm 2 Resources in Cash	0.0316	0.0304	0.0419	0.0462

(Table continued)

MODELS VARIABLES	(24)	(25)	(26)	(27)
	(0.0498)	(0.0499)	(0.0502)	(0.0502)
Firm 1 Performance (income)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Performance (income)	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 1 Leverage (debt)	-0.1579***	-0.1585***	-0.1567***	-0.1568***
	(0.0141)	(0.0142)	(0.0141)	(0.0141)
Firm 2 Leverage (debt)	-0.1358***	-0.1373***	-0.1332***	-0.1331***
	(0.0157)	(0.0157)	(0.0157)	(0.0157)
Firm 1 Mkt Share	-0.5939**	-0.6134**	-0.6756***	-0.6867***
	(0.2546)	(0.2550)	(0.2544)	(0.2547)
Firm 2 Mkt Share	-0.4094	-0.4299	-0.4249	-0.4130
	(0.2624)	(0.2628)	(0.2612)	(0.2614)
Firm 1 Patent stock (5yr)	0.0000*	0.0000*	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Patent stock (5yr)	0.0002***	0.0002***	0.0002***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 1's patents (5yr)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 2's patents (5yr)	-0.0000**	-0.0000**	-0.0000**	-0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant	-5.6507***	-5.4188***	-5.1787***	-5.1989***
	(0.4581)	(0.4869)	(0.4898)	(0.4900)
Observations	20807	20807	20807	20807
Number of dyads	5678	5678	5678	5678
Log likelihood	-4517	-4516	-4509	-4507
Chi-square	1279	1282	1304	1304

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

TABLE 17: Essay Two. Results for Hypothesis 3. Involvement as technical documents, controlling for opposition.

Dependent variable is Number of alliances between firm i and firm j in a year. Panel Poisson regression models with random effects.

MODELS VARIABLES	(28)	(29)	(30)	(31)
Tech. network position asymmetry dyad:		-0.1400 (0.0899)	-0.1525* (0.0896)	-0.2297** (0.0952)
Asymmetry in contribution (tech. docs.) to standard			-0.3346*** (0.0867)	-0.2423*** (0.0939)
Asymmetry in contrib. to standard X Tech. network position asymmetry				0.3345*** (0.1289)
CONTROLS				
Tech. network low centrality dyad	-0.0232 (0.1545)	-0.1452 (0.1733)	-0.1561 (0.1732)	-0.1667 (0.1732)
Low contribution dyad	-0.3009*** (0.0712)	-0.3080*** (0.0713)	-0.6158*** (0.1065)	-0.5953*** (0.1072)
Alliance network low centrality dyad	0.0616 (0.1034)	0.0562 (0.1034)	0.0589 (0.1031)	0.0629 (0.1033)
Alliance network position asymmetry dyad	-0.1036 (0.0684)	-0.1017 (0.0684)	-0.1002 (0.0683)	-0.0952 (0.0684)
Prior alliances between Firm 1 & 2	0.5768*** (0.1047)	0.5610*** (0.1050)	0.5483*** (0.1046)	0.5386*** (0.1048)
Product-market similarity Firm 1 & 2	0.4349*** (0.1416)	0.4321*** (0.1416)	0.4302*** (0.1405)	0.4313*** (0.1408)
Opposition to standard Firm 1	0.0578*** (0.0146)	0.0594*** (0.0146)	0.0552*** (0.0147)	0.0550*** (0.0147)
Opposition to standard Firm 2	0.0068 (0.0179)	0.0074 (0.0179)	0.0022 (0.0181)	0.0022 (0.0181)
Firm 1 Assets	0.2001** (0.0915)	0.2005** (0.0914)	0.2074** (0.0913)	0.2070** (0.0914)
Firm 2 Assets	-0.1461 (0.0926)	-0.1391 (0.0929)	-0.1368 (0.0927)	-0.1360 (0.0930)
Firm 1 R&D	0.2611*** (0.0751)	0.2574*** (0.0751)	0.2593*** (0.0748)	0.2567*** (0.0749)
Firm 2 R&D	0.2128** (0.0910)	0.1987** (0.0915)	0.2006** (0.0913)	0.1987** (0.0915)
Firm 1 Capital Exp	0.0605 (0.0506)	0.0611 (0.0506)	0.0518 (0.0505)	0.0535 (0.0506)
Firm 2 Capital Exp	0.2881*** (0.0522)	0.2877*** (0.0523)	0.2778*** (0.0522)	0.2760*** (0.0524)

(Table continued)

VARIABLES / MODELS	(28)	(29)	(30)	(31)
Firm 1 Resources in Cash	-0.1213***	-0.1294***	-0.1341***	-0.1342***
	(0.0336)	(0.0340)	(0.0339)	(0.0341)
Firm 2 Resources in Cash	0.0313	0.0297	0.0404	0.0431
	(0.0499)	(0.0499)	(0.0499)	(0.0501)
Firm 1 Performance (income)	0.0000**	0.0000**	0.0000**	0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Performance (income)	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 1 Leverage (debt)	-0.1582***	-0.1592***	-0.1527***	-0.1531***
	(0.0139)	(0.0139)	(0.0140)	(0.0141)
Firm 2 Leverage (debt)	-0.1380***	-0.1397***	-0.1380***	-0.1376***
	(0.0156)	(0.0156)	(0.0155)	(0.0156)
Firm 1 Mkt Share	-0.5788**	-0.5969**	-0.5582**	-0.5567**
	(0.2534)	(0.2537)	(0.2526)	(0.2533)
Firm 2 Mkt Share	-0.3939	-0.4175	-0.4295*	-0.4221
	(0.2616)	(0.2622)	(0.2608)	(0.2613)
Firm 1 Patent stock (5yr)	0.0001**	0.0000**	0.0000*	0.0000*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm 2 Patent stock (5yr)	0.0002***	0.0002***	0.0001***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 1's patents (5yr)	0.0000***	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Citations to firm 2's patents (5yr)	-0.0000*	-0.0000*	-0.0000	-0.0000*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant	-5.6377***	-5.3794***	-5.1661***	-5.1840***
	(0.4574)	(0.4857)	(0.4865)	(0.4877)
Observations	20807	20807	20807	20807
Number of dyads	5678	5678	5678	5678
Log likelihood	-4507	-4506	-4499	-4495
Chi-square	1298	1300	1325	1322

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Graphical interpretation of results

Figure 4 and Figure 5 below graphically show the results of the hypotheses tests. In Figure 4, *Technological network centrality* (Hypothesis 1) and *Involvement* (Hypothesis 2) are plotted against the likelihood of alliance formation for three different values of the respective independent variables - Low (Mean minus 1.5 standard deviations), Average (Mean) and High (Mean plus 1.5 standard deviations). The figure reiterates the results discussed above, showing that the likelihood of alliance formation more than doubles as *Technological network centrality* goes from Low to High, and increases by about 50% as *Involvement* goes from Low to High.

In Figure 5, *Asymmetry in Technological network position* is plotted against *Alliance formation rate* first for different categories of *Asymmetry in opposition* and then for different categories of *Asymmetry in proposals contribution*. The plots show that the alliance formation rate between firms is higher as the asymmetry between them increases in both the technological network position and opposition/ involvement in the standard.

Figure 4: Graphical representation of results from Hypothesis 1 and 2 (Essay Two)

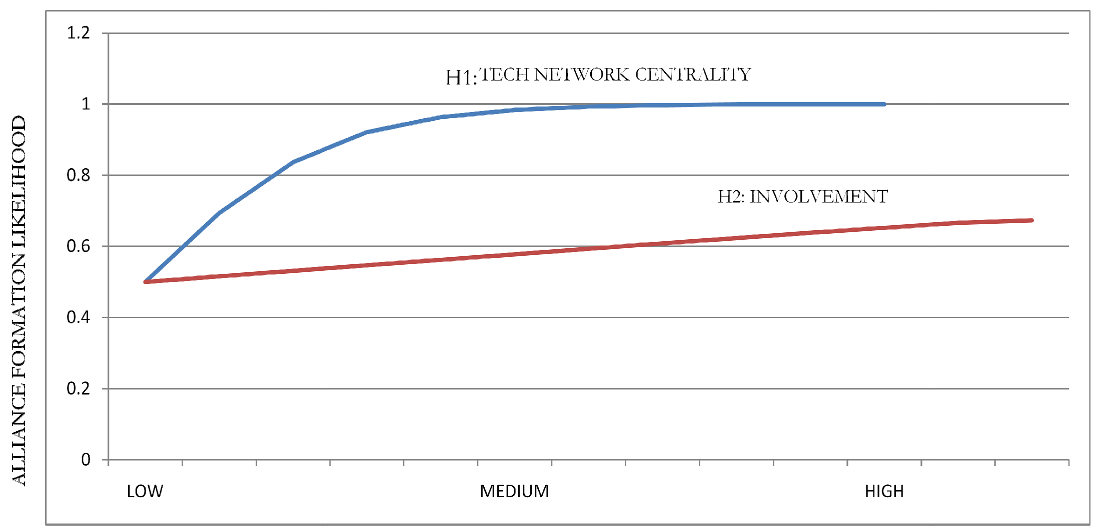
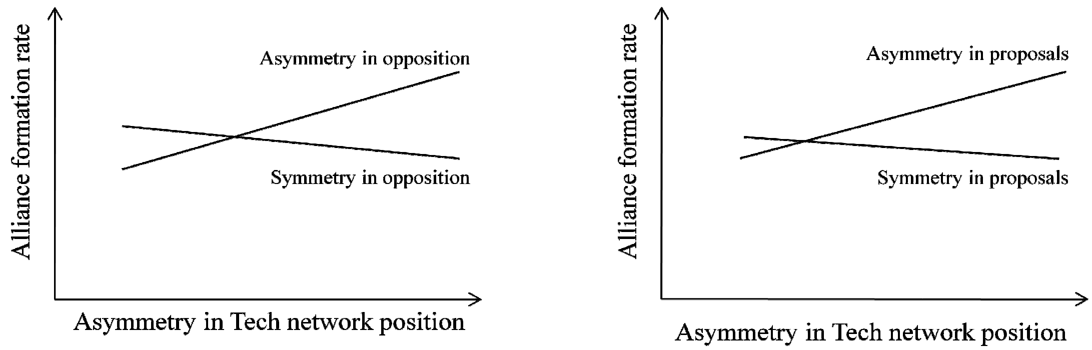


Figure 5: Graphical representation of results from Hypothesis 3 (Essay Two)



Discussion and Contributions

In this paper, I investigated the factors leading to strategic collaboration ties between member firms that participate together in standards-setting committees. I first attempted to understand why some firms might be more attractive, in general, as alliance partners for other member firms. Here, my results support the hypothesis that firms that are the creators of the foundational technologies within the community of member firms in the standards-setting committee, are also more attractive as alliance partners. Specifically, I find that firms that are more central in the technological knowledge network of member firms, as measured by patent citations between the inventions of these firms, also experience a higher likelihood of alliance formation with other firms in the committee. This result is consistent with prior studies that have established a link between technological centrality and collaboration opportunities (e.g. Stuart , 2000).

My subsequent emphasis was on developing a more nuanced understanding of how the technological asymmetries precipitated by an emerging standards agreement might create a compelling rationale for strategic relationships to form. Here, I find that amongst all the possible combinations of alliance ties that might form (between firms that are concurrent members), those between firms that are divergent in their technological knowledge relative to peer firms in the committee *and* divergent in their involvement within the committee are *more* likely. Specifically, the asymmetry between their technological network centrality positions and the asymmetry in their nature of involvement in the committee together predict higher rates of alliance formation. This finding is robust to several alternate measures of involvement, including support (opposition to) for the standard on ballot measures, technical contributions, proposal contributions and overall documents submitted into the standard.

These findings are important because while they in part reiterate findings from prior work on alliance formation in related contexts (e.g. Rosenkopf et al, 2001; Stuart, 2000), they also suggest an entirely new mechanism or motive behind these collaborations. While research has discussed resource-based motives (financial and technological capital as resource drivers) and sociological motives (social capital, relational capital) of alliance formation, the mechanism or motive behind alliance formation in this context may be considered as one of "political" capital. On the one hand technologically central firms in the standards committee are more influential in driving the specifications of the standard as the knowledge they possess is at the core of the community of firms that is attempting to negotiate a shared technical agreement. But, on the other hand, arriving at a standards agreement is not necessarily the "end-game" in contexts of technological change where network externalities drive the eventual success of the standard. Merely achieving the minimum majority required to formally channel a standard through the committee may result in the quick passage of the standard, but may also irreversibly affect its legitimacy (cf. Garud et al, 2002). This may have detrimental effects on the adoption of the standard by affecting the investments that other firms make in complementary products and technologies. Thus, these firms may be particularly incentivized to boost the legitimacy of the standard by creating bridging ties with the peripheral players.

The findings also reveal that it is not merely the asymmetry in the technological network that drives these connections but also the divergence in the involvement - in other words central firms create these linkages with other members that are not only disadvantaged by the standard but are also actively opposing it or limiting their technical involvement. This finding is also consistent with prior work that has proposed that alliances may form when firms are in vulnerable strategic positions or when they are attempting pioneering technical strategies (Eisenhardt and Schoonhoven, 1996). Firms that are disadvantaged technologically because of the emerging standard may perceive their positions to be increasingly vulnerable as the standard-setting process progresses, and this might spur their collaboration-seeking behavior with the more central players on the standards committee.

These findings offer several important implications and insights for research on alliances, technological change and strategic networks.

First, this study contributes to the nascent literature on heterogeneity of benefits and opportunities that accrue to firms participating in multi-partner alliances (Lavie et al, 2007). Further, by linking these opportunities to asymmetries in firms' involvement and their technological positions, this study also provides evidence that dynamic capabilities can encompass not just adaptation to technological change but also control of the change itself (Teece, 2007).

Second, this study makes a contribution to the alliance formation literature. An emerging body of work (e.g. Ahuja et al, 2009) has begun to investigate how firms at the periphery of a network can form linkages with the core. But this work has not explicitly discussed the *mechanisms* or the *incentives* undergirding such outcomes. For example, Stuart (1998) notes that alliance data in high technology industries contain many associations between high technological prestige and low technological prestige firms, but does not explicate the mechanisms that lead to such asymmetric ties being formed. Similarly, Stuart and Podolny (1996) note that alliances are possible strategies for firms to bring about significant shifts in technological focus – using the example of Mitsubishi that moved towards the technological core in the semiconductor industry by formulating alliances with firms in the core, they call for future research that investigates the effect of alliance strategies on the amount and direction of firms' search. By highlighting that the heterogeneity in benefits to participation in standards committees may arise from both firms' structural positions and the nature of firms' involvement in these alliances, this study provides both the conceptual logic explicating such mechanisms and an empirical test of these propositions.

Further, in contrast with prior studies, the arguments and findings in this paper operate across two different network structures, and thus emphasize the importance of considering the multiplicity of ties across these structures when studying inter-organizational relations (Gulati, Kilduff, Li, Shipilov and Tsai, 2011). These findings also underscore a more subtle point that one way to conceptualize multiplicity may be to look at the relationship between the disparities between actors in one relational structure on tie formation between the same set of actors in a parallel relational structure.

Finally, at a broader level, this study provides evidence on how networks may learn to coordinate in the absence of authority (Kogut, 2000). Technical standards setting committees provide a context where although the structure or landscape of firms' technologies may still largely determine technological benefits and relational opportunities, the importance of achieving a timely consensus may create endogenous opportunities for tie formation in the network.

Limitations

The above findings and related discussion points must be interpreted keeping in mind the limitations of this study. While this paper provides robust empirical evidence of tie formation to support the theoretical arguments, it does not actually measure the effect of such ties on future consensus formation efforts in the committee. In other words, it does not look at whether the disadvantaged firms that were induced into collaborations by the central players actually reduced their opposition and increased their involvement in the committee.

CHAPTER 5: ESSAY THREE - CLOSING THE DOOR ON OPEN STANDARDS?

While Essay One and Essay Two explore strategic choices and outcomes *within* a particular technological standards organization, this essay examines how firms might strategize *across* two different committees that develop overlapping technological standards. In particular, using an inter-organizational conceptual lens, this paper investigates which firms are likely be members in both these multi-firm standards organizations and, further, how they might make decisions around products and technologies based on these standards.

Background and motivation

Many competitive settings are characterized by the simultaneous presence of numerous multi-firm organizational arrangements, often with overlapping and even competing interests. The limited academic research on these multi-firm arrangements has referred to them variably - as competing alliance networks, constellations, strategic blocks, alliance groups, multipartner alliances or simply as consortia (Nohria and Garcia-Pont, 1991; Gomes-Casseres, 1996; Das and Teng, 2002; Sakakibara, 2002; Lavie et al, 2007; Lazzarini, 2007). Depending upon the specific setting, these types of arrangements may be constituted either by mutually exclusive or by overlapping member firms. For example, in the airline industry, the two major operating alliances – Star Alliance and One World – have mutually exclusive memberships and these alliances directly compete with one another. In contrast, especially in environments characterized by frequent technological change, arrangements with overlapping firm memberships have become increasingly common. For example, in the wireless telecommunications setting, the CDMA Development Group, the Wi-Fi Alliance and the WiMax Forum are three different organizational groups that have overlapping member firms, all focused on the development of wireless technology, but each based on different assumptions. Table 18 shows a partial list of such multi-firm initiatives which Intel Corporation is a part of (Source: Intel website).

TABLE 18: Essay Three. Participation in multi-firm technology alliances - Intel example

Computing and consumer electronics standards
– 4C, Advanced Access Content System (AACS), Association of Radio Industries and Businesses (ARIB), China DRM Forum, Consumer Electronics Association, Consumer Electronics Linux Forum (CELF), Digital Living Network Alliance (DLNA), Digital Video Broadcasting Project (DVB), Digital Transmission Content Protection (DTCP), Distributed Management Task Force (DMTF), DVD Forum, High-bandwidth Digital Content Protection (HDCP), High-Definition Multimedia Interface (HDMI), HomeGrid Forum, IBIS Open Forum , Intel® High Definition Audio Specification, The Linux Foundation , PCI Industrial Computer Manufacturers Group (PICMG), SCSI TA, Serial ATA International Organization (SATA-IO), Trusted Computing Group, USB Implementers Forum (USB-IF), UPnP* Forum
Silicon and semiconductor standards
– Association of Super-Advanced Electronics Technologies, Focus Center Research Program, SEMATECH, Interuniversity Microelectronics Center, JEDEC Solid State Technology Association, National Association of Manufacturers (NAM), International Electronics Manufacturing Initiative(iNEMI), Semiconductor Equipment and Materials International* (SEMI), Semiconductor Research Corporation
Software and Web standards
– The Linux Foundation, The Internet Engineering Task Force (IETF), OASIS, Web Services Interoperability Organization, World Wide Web Consortium (W3C)
Networking and communications standards
– IEEE 802.3, IEEE 802.17, InfiniBand Trade Association, The Internet Engineering Task Force (IETF), PCI-SIG, Serial ATA, Storage Networking Industry Association (SNIA), UPnP Forum, Bluetooth SIG, IEEE 802.11, IEEE 802.16, WiMAX, Wi-Fi Alliance Telecommunications, 3rd Generation Partnership Project (3GPP), Alliance for Telecommunications Industry Solutions, European Telecommunications Standards Institute (ETSI), GSM Association, International Telecommunication Union (ITU), Open Mobile Alliance (OMA), PCI Industrial Computers Manufacturing Group (PICMG), SCOPE Alliance, Telcordia

These multi-firm organizations in technological change settings are further marked by varying development processes and governance mechanisms (cf. Aldrich and Sasaki, 1995; cf. Borys and Jemison, 1989). Whereas some committees develop technology standards openly through a voluntary, consensus-driven process with decentralized committee-level governance and without a vested sponsor's backing (example of INCITS in Essay One and Essay Two), others restrict the definition and maintenance of the standard's core technology to a few sponsor firms while only allowing non-sponsors to augment the core to implement certified products on the standard (example of USB standard owned by Intel or the AAC audio format standard owned by AT&T and others).

A powerful incumbent firm may see a distinct competitive advantage in sponsoring an organization that develops a standard based on its proprietary technology. In a dynamic environment, timing and speed are essential for an incumbent firm to appropriate returns on its R&D investment (Teece, 1986). Sponsor or promoter-backed technology organizations may be able to diffuse the standard at a faster rate than voluntary standards committees. As sponsor-backed standards are tightly coupled with the sponsor's technology, they tend to have a narrower scope that is circumscribed by the technological capabilities of the sponsor firm. In other words, the objective of the standard is not necessarily to achieve the best technologically possible solution by evaluating the merits of alternative solutions across several firms, but to create an industry standard around the sponsor's proprietary technology. Further, these organizations do not need to form a consensus around what constitutes the standard - the sponsor firms set the technical agenda and timelines for the release standard. In contrast, a large number of conflicted firms need to arrive at a consensus on the standards' specifications in voluntary standards committees, often causing delays and slowdowns in the adoption of the standard (Simcoe, 2012).

However, sponsor backing may also cause a standard to suffer from legitimacy problems (e.g. Garud et al, 2002). Perceptions may arise amongst industry participants that the specifications have been manipulated opportunistically to merely consolidate or enhance the market positions of the sponsors (Garud et al, 2002). The potential for disproportionate value appropriation by sponsor firms (cf. Teece, 1986; West, 2003) may stymie the adoption of such standards, as other firms may not readily commit to developing standard-compliant products. Thus, the critical network externality benefits to adopting the technology (Katz and Shapiro, 1986) may be hindered by limited product variety and availability, and the standard may fail to become widely accepted. In contrast, although voluntary committees take a longer time to reach a consensus (Simcoe, 2012), their open development processes bolster the legitimacy of the developed standard and facilitate adoption and diffusion. Thus, ultimately, the market success of a particular standard may arise not because of its technological superiority, but from the level of organizational support that the technology attracts (cf. Wade, 1995).

An important question then is how is a sponsor-backed technology standards organization, able to orchestrate a network of firms that build on the standard (Dhanaraj and Parkhe, 2006)? In this essay, I explore this question by studying firm-level decisions to contribute to a sponsor-backed standard. I specifically look at an empirical setting (as described in Chapter 2) where firms are overlapping members in an existing voluntary standards committee in the same technological area. This allows me to simultaneously explore the dynamics of competition between different types of standards organizations (West, 2003) and coordination within a particular standards organization, both of which I argue are closely linked.

My hypotheses, developed below, argue that firms' decisions across standards organizations are driven by two types of inter-organizational considerations: (1) A firm's prior linkages with the sponsor firms - technological and relational - which reveals the extent to which a firm's capabilities and incentives align with the sponsor's developing technological trajectory, and (2) A firm's position in the technological knowledge network of member firms in the voluntary standards committee, which indicates the extent to which a firm stands to benefit from a competing technological trajectory.

Theoretical Arguments

I hypothesize about the antecedents of three different decisions firms make with regard to a competing sponsor-backed standard: the decision to join the sponsor backed standards organization (membership), the decision to introduce standard compliant technology components (products) and the decision to claim exclusive rights on technologies that are based on the standard (patents). While membership allows us to understand the drivers behind network orchestration, investigating product development and patenting decisions provides a richer understanding of the adoption and diffusion of the standard.

(1) Overlapping membership in the sponsor-backed standards organization

At the dyadic level, a large body of research on alliance formation has suggested that firms are brought together in collaborative relationships because of strategic interdependence reasons (e.g. Oliver, 1990; Gulati, 1995), complementarity motives (e.g. Chung, Singh and Lee, 2000) or similarities in status or network positions (Podolny, 1994; Gulati and Gargiulo, 1999). Standards bodies are multilateral collaborations that operate differently from dyadic relationships. With dyadic ties, matching of resources is a reasonable conceptualization of network tie formation (e.g. Mitsuhashi and Greve, 2009). But the size of the standards organization, which in itself is a large affiliation network (e.g. the USB Implementers Forum has over 800 member firms), makes large-scale resource matching or homophily-based matching less likely. Further, sponsor firms are unlikely to be seek particular technological complementarities with potential firms to develop the standard. Sponsors solicit the participation of outside firms primarily to encourage the adoption of the standard and not to develop it. In other words, sponsor firms are unlikely to discriminate on membership based on the characteristics of specific firms - the greater the number of firms that join and adopt the standard, the higher the chances of its adoption and subsequent success for the sponsors.

It is therefore essential to consider which of the firms that are in the voluntary standards committee would actually be attracted to joining a competing sponsor-backed standard. As the technology of a sponsor-backed standard does center around the technology of the sponsor firms, the linkages between a focal firm's technology and the sponsor firms' technologies are likely to have an important bearing on any firm's membership decision to join the sponsor-backed standard. These linkages reveal the extent to which a firm’s technological knowledge is closely tied with that of the sponsor firms (e.g. Stuart and Podolny, 1996). A large body of research has argued that firms' strategic choices are path-dependent (Nelson and Winter, 1982) and that a firm's prior technological knowledge provides options for future growth (Kogut and Zander, 1992). A firm’s direction of technological search is thus strongly constrained and driven by its prior technological competencies (Patel and Pavitt, 1997; Stuart and Podolny, 1996; Rosenkopf and Almeida, 2003). Thus, the extent to which a firm's technological competencies have built on sponsor firms' technological knowledge is likely to weigh in on its decision to participate in a standards organization controlled by these sponsor firms.

The more a firm's technological competencies utilize the sponsor firms' technologies as a foundation, the more likely that a new technological standard developed by these sponsor firms will materially affect the future value of these competencies. The new sponsor-backed standard may reveal important architectural shifts that could render such a firm's competencies obsolete if it does not make the necessary investments to incorporate these changes (Henderson and Clark, 1990). By joining the standards body, the firm may be able to obtain early access to the knowledge needed to make these strategic changes. Beyond accessing early versions of this knowledge, it may also be exposed to discussions that reveal the tacit knowhow required to successfully develop and certify products on the standard. These benefits make a firm that is closer technologically to the sponsor firms to be more likely to seek membership in the sponsor-backed technology alliance, relative to a firm whose knowledge is decoupled or distant from those of the sponsor firms. Thus, I hypothesize:

> *Hypothesis 1: Higher (lower) technological linkages to the sponsor firms will increase (decrease) the likelihood of membership in the sponsor-backed standards organization.*

Firms with prior strategic alliance ties to the sponsor firms are also more likely to join the sponsor-backed standards body. Research on alliances and networks has consistently shown that prior alliances are a predictor of future collaborations between firms (e.g. Gulati and Gargiulo, 1999; Gulati, 1995b). Prior relationships lead to the development of trust (Gulati, 1995a) which allows firms to mitigate appropriation concerns in future collaborations (Gulati and Singh, 1998). Firms that have accumulated relational capital with the sponsor firms will therefore be less concerned that the standard will lead to disproportionate value capture by the sponsors. Furthermore, partner-specific experience in the form of routines, assets and tacit knowledge may be a source of competitive advantage that can be leveraged through future repeated relationships (Gulati, Lavie and Singh, 2009; Dyer and Singh, 1998). Membership in the sponsor-backed standards alliance may be a route to obtaining these future collaborations as the sponsor firms enter into contractual agreements to license the standard's technologies. Thus,

Hypothesis 2: Higher (lower) relational linkages to the sponsor firms will increase (decrease) the likelihood of membership in the sponsor-backed standards organization.

Beyond technological and relational linkages with the sponsors, a firm also needs to consider whether supporting the sponsor-backed standard would lead to an erosion of its current position. From Essay One, firms that are more central in the technological knowledge network of the competing voluntary standards committee are more committed to supporting that standard. The foundational nature of their knowledge in the voluntary standards committee ensures that the rules that emerge from this committee build upon their knowledge, thus strengthening their technological position. Building on Essay Two, their strategies to accelerate consensus formation and broaden the involvement of firms in the committee indicate commitments to the success of that standard. Thus, the more technologically central the firm is in the voluntary standards committee, the more likely its focus is likely to be on ensuring the success of this standard relative to other competing standards. Given the nature of network externalities and the bandwagon effect membership can have, by joining the sponsor-backed standard such a firm only risks increasing the chances that the competing standard will succeed at the expense of the voluntary standard.

In contrast, technologically peripheral firms in the voluntary standards committee will be more inclined to explore membership in the competing sponsor-backed standard. Building on Essay One, the tangential nature of their knowledge and consequently their limited influence in the competing standards committee may dilute their commitment to the success of the voluntary standard. Recent research has also found evidence that peripheral players in the network are more likely to seek membership in such multi-firm organizations (Rosenkopf and Padula, 2008), potentially looking to increase the likelihood of liquidity events (Waguespack and Fleming, 2009). Peripheral firms are more likely to be startups with novel, exploratory ideas that are tangential to the voluntary standards committee. They may seek external visibility to develop and market their technology. Sponsor-backed standards may provide such opportunities where these firms can showcase their technologies to many potential partners or leverage the media publicity provided to certified products (Lavie et al, 2007). Thus:

Hypothesis 3: Higher (lower) technological knowledge network centrality in the voluntary standards committee will be associated with a lower (higher) likelihood of membership in the sponsor-backed standards organization.

(2) Product development on the sponsor-backed standard

Firms also need to make strategic decisions about developing products based on the standard. Product development on the standard indicates both the capability to understand the technological knowledge associated with the standard in order to build a compliant product, and a substantial organizational commitment towards diffusing the standard. Firms that have a history of strategic alliance partnerships with the sponsor firms - i.e. extensive business linkages by virtue of technology licensing agreements, joint research partnerships or sole-sourcing contracts - will possess both the capabilities and the strategic incentives to make such a commitment. First, prior alliances provide for a fine-grained mechanism to access sponsor firms' technological knowledge (Grant and Baden-Fuller, 2004), especially the tacit aspects of this knowledge that are difficult to transfer (Szulanski, 1996). Thus, a firm with a past history of ties to sponsors is likely to have a more nuanced understanding of the sponsor firms' foundational knowledge. Second, these relationships also increase a firm's partner-specific absorptive capacity with the sponsor firms (Dyer and Singh, 1998; Lane and Lubatkin, 1998; Zaheer, Hernandez and Banerjee, 2010), which enhances its ability to understand and apply the new knowledge from the technical standard, also a sponsor firm creation. Finally, by taking advantage of established sponsor-specific organizational routines (Zollo, Reuer and Singh, 2002), such a firm will also be able to obtain faster access to such knowledge.

A higher incidence of prior strategic alliances with sponsor firms also increases the firm's strategic incentives to introduce products supporting the standard. First, these relationships increase the likelihood that subsequent products will be high-performing (Soh, 2003), thus providing a return-on-investment motive for firms. Second, the concentration of a firm’s relational capital amongst sponsor firms suggests that these firms control both access and affiliation benefits for the focal firm in the network (Koka and Prescott, 2008). In other words, the sponsor firms control not only tangible resource flows (such as technology licenses) to the focal firm, but also intangible resources, including information about potential business opportunities, awareness of the quality of other partners in their network, and knowledge about technology trends. As Lavie et al (2007) note, organizationally involved partners that engage in product certification demonstrate genuine interest in and commitment to the activities and agenda of the multi-partner alliance. By demonstrating such commitment, firms that are relationally dependent on the sponsor firms will continue to obtain the benefits of their prior relationships. On the other hand, by not implementing the standard, such a focal firm could jeopardize both current and future sources of revenue and limit opportunities to expand its inter-firm network beyond these sponsor firms, thus leaving it vulnerable to unforeseen technological shocks (Uzzi, 1997). It is important to note that even though the sponsor-backed standard may not be entirely favorable *technologically* to the firm, it may still need to develop certified products based on the standard to ensure a continued flow of these resources. The nature of these strategic pressures is consistent with prior research on technological change that has shown how existing external commitments often supersede technological considerations (e.g. Christensen and Bower, 1996). Thus:

Hypothesis 4: Higher (lower) relational linkages to the sponsor firms will be associated with a higher (lower) rate of products supporting the sponsor-backed standard

In contrast with the effect of prior relational ties with sponsor firms, the more central a firm is in the voluntary standards committee, the lower incentives it has to introduce standard compliant products on the sponsor-backed standard. Although the product contribution of any firm benefits the alliance sponsors by augmenting network externality effects of the underlying technology, those of technologically prominent firms from the competing voluntary standard may *accelerate* adoption. Their decision to make substantial contributions to a competing standard may signal an important technological shift to the other (less central) firms in the voluntary standards committee, potentially triggering a bandwagon effect (Abrahamson and Rosenkopf, 1993; Westphal, Gulati and Shortell, 1997). The prominence of these firms may further serve as an endorsement to the sponsors (cf. Gulati and Higgins, 2003) thus bolstering the legitimacy of the standard. All these factors increase the likelihood that the sponsor-backed standard will become dominant at the expense of the voluntary standard.

On the other hand, firms that are the most technologically peripheral in the voluntary standards committee will have the greatest incentives to develop and certify products that support the sponsor standard. The peripheral nature of their knowledge in the competing standard suggests that the rules that emerge from this standard are unlikely to favor their technology and thus these firms are more prone to orchestration efforts by the sponsor firms (cf. Dhanaraj and Parkhe, 2006). Thus:

Hypothesis 5: Higher (lower) technological knowledge network centrality in the voluntary standards committee will be associated with a lower (higher) rate of products supporting the sponsor-backed standard

<u>(3) Patenting the sponsor-backed standard's technologies</u>

While increasing membership and new product introductions both contribute the success of the sponsor-backed standard, the extensive patenting of technologies related to the sponsor-backed standard may have an opposing effect. Patenting may discourage development and adoption of the technology, especially by smaller firms and startups that have limited resources to battle intellectual property lawsuits or to redesign products around patents in order to avoid patent infringement problems. Recent research on IP law has extensively discussed how technology standards consortia are increasingly witnessing holdups due to such infringement claims and unreasonable royalty requests (Shapiro, 2001; Lemley, 2002; Lemley and Shapiro, 2007; Farrell et al, 2007). Although patents have an important function of providing intellectual property protection to firms developing products and technologies on the standard, sponsor firms need to balance it with the network externality benefits they stand to gain when the standard diffuses widely, creating a lock-in for suppliers and consumers (Arthur, 1989). For example, in the personal computer industry, the IBM-Wintel architecture by virtue of being open and easily replicable, quickly became dominant while other proprietary and patented architectures lost out. Relinquishing royalties on intellectual property has been documented as one of the cornerstones of Intel's successful platform leadership strategy (Gawer and Cusumano, 2002). Similarly, Khazam and Mowery (1994) discuss, with the example of the Reduced Instruction Set Computing (RISC) architecture, how the innovator may gain significant advantages by "giving away" important intellectual property.

Thus, it follows that sponsor firms backing the standard are likely to discourage excessive patenting of technologies based on the standard. It further follows that firms that are more tied *technologically* with the sponsors would similarly be more judicious about patenting and risking the slowdown of the standard. Firms' abilities to develop technologically similar inventions reveal similar underlying innovative capabilities and the clustering of strategic groups (Stuart and Podolny, 1996). These will be firms who have a shared technological interest in the adoption of the standard as the overlap in their technological capabilities with those of the sponsors suggests that the standard's success will confer them with spillover benefits. On the other hand, firms that are not linked (or less tied) with the sponsor firms have technological capabilities that are divergent and at the extreme, these capabilities could be rendered obsolete by the diffusion of the sponsors' standard. Patenting on the sponsor-backed standard may function not only as an option to slow down its emergence but also as a hedge and potential royalty stream if the standard succeeds. Therefore, I hypothesize:

Hypothesis 6: Higher (lower) technological linkages with the sponsor firms will be associated with a lower (higher) rate of patenting on the sponsor-backed standard

Similarly, firms that are more technologically central in the competing voluntary standards committee will have higher incentives to patent. For these firms, patenting on the sponsor-backed standard may endow them with bargaining power to negotiate favorably with the sponsors (cf. Cohen, Nelson and Walsh, 2000; Reitzig, 2003; Ziedonis, 2003; Ziedonis, 2004). These negotiations may be about the nature of the standard's technical specifications (which are tightly controlled by the sponsors), its certification and testing processes, as well as future licensing and technology development opportunities based on the standard. The recent patent battles in wireless technologies indicate the increasing importance for firms to invest in intellectual property rights as a defense mechanism to obtain leverage in such negotiations (Rusli and Miller, 2011; Womack and Tracer, 2011; Crovitz, 2011).

Greater technological centrality in a competing standards committee also makes these firms more attractive for the sponsors from a coalition orchestration standpoint. Patenting by these firms is therefore less likely to be met with retaliation or litigation than patenting by technologically peripheral firms. Technologically central firms may also use patents to hedge against the uncertainty that either standard could succeed, thus deriving influence and benefits if one succeeds and accumulating royalties and bargaining power if the other achieves dominance (Hatfield, Tegarden and Echols, 2001). Thus:

Hypothesis 7: Higher (lower) technological knowledge network centrality in the voluntary standards committee will be associated with a higher (lower) rate of patenting on the sponsor-backed standard

Empirical Approach

As described in Chapter 2, I test the above arguments by analyzing the membership, product introduction and patenting decisions of firms from the INCITS voluntary standards committee, on the USB Implementers Forum - an overlapping sponsor-backed standards body.

Data Sources and Measures

In addition to the data sources for the INCITS standards committees participation measures (INCITS electronic resources), technological network and patent measures (NBER), alliance information (Factiva) and firm financials (Compustat and others) that I have described in Essays One and Two, I collected detailed data on the USB Implementers Forum standards body using Wayback machine and the standards organization's online resources at www.usb.org. Due to technical limitations with the Wayback Machine, membership data was only available from 1999 to 2005 and then 2009 onwards - I treat the intervening years as missing data. The USB-IF provides information on all standard compliant product introduction by its member firms. This information includes the name of the firm, category of the product and the date of introduction. I manually matched the names of the member firms in the membership roster and in the product introduction list, with the names of the member firms in the INCITS standards committee to get an integrated sample.

I used the Derwent database (Henderson & Cockburn, 1994) to obtain information on firms' patenting activities on both the USB and the INCITS standards. Derwent facilitated keyword-driven searching of the patent database as opposed to the NBER patent dataset. Derwent also provided current year patent data in contrast with NBER that has the parsed patent dataset only up until 2006. I used various combinations of keywords related to the USB and INCITS technologies to retrieve the patents associated with these standards. For example, the search string for the USB patent retrieval was coded as:

> "USB-IF" OR "Universal Serial Bus Implementors Forum" OR "Universal Serial Bus Implementor Forum" OR "USBIF" OR "USB Implementors Forum" OR "USB-Implementors Forum" OR "USB Implementor Forum" OR "USB-Implementor Forum" OR "Universal Serial Bus-IF" OR "Universal Serial Bus Implementers Forum" OR "Universal Serial Bus Implementer Forum" OR "USB Implementers Forum" OR "USB-Implementers Forum" OR "USB Implementer Forum" OR "USB-Implementer Forum" OR "USB-certified" OR "USB certified" OR "Universal Serial Bus"

I used a combination of automated and manual matching techniques to map the patent assignees from these patents to the member firms of the INCITS standards committee in order to obtain the set of patent claims from the overlapping member firms.

<u>Dependent variables:</u> I hypothesize on three different dependent variables and they are operationalized as follows:

(i) Membership in USB standard (Hypothesis 1, 2 and 3) - This is a binary variable that is set to 1 if an INCITS member firm became a member of the USB standard in a particular year and 0 otherwise. Firms enter the risk set when they become members of the INCITS standards committee and either leave the risk set when they become members of the USB standard or are included (as right-censored data) up until the final observation year.

(ii) Product contribution in USB standard (Hypothesis 4 and 5) - Products were reported under several categories including Systems, Embedded Hosts, Device Wire Adapters, Host Wire Adapters, Hubs, Cable Assemblies and Connectors, Hubs, Hubs Silicon, Peripherals, Peripheral Silicon, OTG Device and OTG IP Building Blocks. Each of these categories were further reported under several sub-categories - for instance Cable Assemblies and Connectors consisted of Receptacle, Plug and Cable Assembly . The product contribution variable was calculated by summing up the count of all the compliant products introduced by an INCITS member firm on the USB standard, across all categories and sub-categories.

(iii) Patent claims on USB standard (Hypothesis 6 and 7) - This is a yearly count of all approved patent claims for an INCITS member firm on the USB standard.

Independent variables:

There are three main independent variables and they are operationalized as follows:

(i) Technological linkages with the USB sponsor firms - This is operationalized as the yearly proportion of all backward citations made to patents owned by one of the sponsor firms of the USB standard (e.g. Song, Almeida and Wu, 2003).

(ii) Relational linkages with the USB sponsor firms - Similar to technological linkages, this is measured as the proportion of all strategic alliance relationships in the preceding year that are with one or more sponsor firms.

(iii) Technological centrality in the competing voluntary standards committee - The technological network centrality was calculated in identical fashion to Essay One and

Essay Two. If a firm was a member in more than one INCITS sub-committee, then its average centrality score across these sub-committees was included.

Using a proportion rather than a count measure to calculate the linkages to sponsor firms allows me to normalize for firm size considerations as well as create constructs that truly reflect the degree to which a focal firm's technological knowledge or relational capital is tied with the sponsor firms. Robustness checks using a count of the number of linkages provided substantively similar results.

<u>Controls:</u>

There can be a number of different factors affecting membership, product and patenting activity on a particular technological standard and I attempt to explicitly control for a host of these factors. I include a control for *Technical proposals contribution in voluntary standard* which measures the number of technical proposal documents that were recorded as authored by one of the firm's representatives, in order to measure existing commitment to the voluntary standard that may arise independent of a firm's network position in that committee. Similarly, I also include *Opposition within voluntary standard* to control for the number of firm votes against proceeding unconditionally with the INCITS standard. I control for *Patents applied for on voluntary standard* which is a simple count of the patents listed on Derwent that matched one of the INCITS technology standard's keywords. This may indicate competing intellectual property and royalty considerations independent of the hypothesized inter-organizational motives. I also control for both *Patent stock* and *Citations to patent stock* that together are measures of a firm's technological capabilities (Hall, Jaffe and Trajtenberg, 2005) - since firms with better technological capabilities are more innovative, they may patent more and /or introduce more new products than firms with inferior technological capabilities. Finally, I control for several firm size, performance and strategy indicators, including *Firm size (assets), Firm R&D, Firm resources (cash), Firm leverage (long term debt)* and *Firm Capital expenditure*, and also for a firm's industry (sector) using indicator variables for the 4-digit SIC codes. All the firm financial measures are logged.

Method

I model the data as an unbalanced panel as membership, product involvement and patent claims in the USB standards varies over the years. I alternatively use both random and firm fixed-effects models to control for unobserved heterogeneity. Random-effects models make a stronger assumption that the unobserved heterogeneity is uncorrelated with the variables of interest. This assumption may not be tenable if there are invariant, unobserved firm characteristics which are correlated with the firm's technological network position, its linkages with sponsor firms and its activities in the USB standard. By using firm-fixed effects models, I can control for these unobserved characteristics to the extent that they are time invariant. However, as firm fixed-effects models condition on within-firm variation only and drop firms that have no variation across time, I also show results with random-effects models also. Finally, I lag all the independent variables and controls by one year to mitigate simultaneity and reverse-causality concerns.

For Hypothesis 1-3, the nature of the dependent variable suggests that the data are censored beyond the observation period. A hazard model is particularly useful in dealing with censoring and time-varying explanatory variables and the necessary estimation procedures to calculate censoring are built into programs such as *stcox* in STATA

(Allison, 1995). Thus, I use a hazard model to estimate the likelihood of membership. The hazard function is defined as:

$$h_i(t) = \lambda_0 e^{\beta x_i(t)} \qquad \text{Or equivalently}$$

$$\log h_i(t) = log\,\lambda_0 + \log \beta x_i(t)$$

Here h_i is the hazard at time ‘t’ for firm ‘i’ to join the USB standard body., x_i is a vector of covariates for firm ‘i’ measured at time ‘t’ and log λ_0 is a function of time that is treated as invariant across the sample cross-section. β is the vector of covariates of interest to be estimated for the firms in the sample. For my dataset, I defined each calendar year to be a distinct time interval. All the independent variables, controls and the dependent variable were measured at the beginning of each calendar year. I use a Cox proportional hazards model that has the advantage of being able to condition out the time-dependent component of the hazard without needing to specify any kind of functional form (Allison, 1995).

For Hypotheses 4 -7, the nature of the dependent variables (yearly count of products and count of patents) implies a Poisson process. However, over-dispersion (standard deviation is more than seven times the mean for products and more than five times the mean for patents) implies that a negative binomial specification is more appropriate to model the data (Hausman, Hall and Griliches, 1984). However, a conditional fixed-effects negative binomial model is not a true fixed-effects model since it fails to control for all its predictors (Allison & Waterman, 2002; Hilbe, 2011). For fixed-effects models, I therefore use conditional fixed-effects quasi-maximum likelihood Poisson regressions. Negative binomial regression models with random and firm-fixed effects yielded substantively similar results. The underlying econometric specification for the fixed-effects Poisson models is as follows:

$$y_{it} = \ ln\,\mu_{it} = \ \delta_i + \beta x_{it}$$

Here $y_{it,}$ is the dependent variable, measured as a count of products introduced by firm 'i' in year 't'(Hypotheses 4 & 5) and a count of patents applied for by firm 'i' in year 't'[11](Hypotheses 6 & 7). This dependent variable follows a Poisson distribution with parameter μ that varies across firms and across time, and is a log-linear function of δ and β . δ is the firm-fixed effect that is time-invariant and firm-variant and β is the vector of coefficients that needs to be estimated for the independent variables x_{it}. The Cox proportional hazard models (Hypotheses 1-3) are estimated using the *stcox* command and the Poisson models (Hypotheses 4-7) are estimated using the *xtpoisson (fe)* command.

Results

Table 19 illustrates the descriptive statistics and correlations for the sample. There appear to be no significant concerns of multicollinearity amongst the variables of interest (i.e. between *Technological linkages to USB standard sponsors*, *Relational linkages to USB standard sponsors* and *Technological network position in voluntary standards committee*) - the highest pairwise correlation is 0.31. Nevertheless, I estimated the variance inflation factors after the main regressions to confirm that VIFs were within limits. The high correlations between the financial variables and amongst the patent variables are expected and do not affect the results for the hypothesized predictors.

[11] Only eventually approved patents are considered

TABLE 19: Essay Three. Descriptive statistics and correlations.

	Variable	Mean	S.D.	1	2	3	4	5	6	7
1	Member in USB standard	0.05	0.21	1						
2	Number of products on USB standard	0.66	4.27	0.19	1					
3	Number of patent claims on USB standard	0.91	5.05	0.36	0.4	1				
4	Relational linkages to USB standard sponsors	0.04	0.2	0.13	0.23	0.28	1			
5	Tech. linkages to USB standard sponsors	0.05	0.13	0.17	0.03	0.1	0.19	1		
6	Tech.network position in voluntary standard	0.05	0.16	0.3	0.16	0.3	0.3	0.31	1	
7	Tech. proposals contribution in voluntary standard	0.07	0.53	0.08	-0.01	0.01	0.12	0.14	0.23	1
8	Opposition within voluntary standard	0.12	0.69	0.06	0	0.04	0.15	0.19	0.31	0.4
9	Patents applied for on voluntary standard	0.19	1.25	0.12	0.1	0.27	0.28	0.15	0.36	0.15
10	Patent stock	356.76	989.02	0.25	0.29	0.54	0.36	0.05	0.39	0.03
11	Citations to patent stock	2586.1	7993.1	0.2	0.25	0.43	0.37	0.12	0.44	0.04
12	Firm size (assets)	7.18	2.45	0.12	0.22	0.26	0.27	0.03	0.3	0.05
13	Firm R&D	4.73	2.11	0.15	0.22	0.3	0.29	0.08	0.33	0.09
14	Firm resources (cash)	5.03	2.31	0.1	0.23	0.26	0.27	0.04	0.31	0.07
15	Firm leverage (long term debt)	4.14	3.29	0.07	0.19	0.23	0.19	-0.03	0.22	0.02
16	Firm Capital exp.	4.19	2.39	0.15	0.23	0.28	0.26	0.06	0.31	0.05

	Variable	8	9	10	11	12	13	14	15	16
8	Opposition within voluntary standard	1								
9	Patents applied for on voluntary standard	0.3	1							
10	Patent stock	0.04	0.3	1						
11	Citations to patent stock	0.07	0.36	0.78	1					
12	Firm size (assets)	0.05	0.19	0.4	0.38	1				
13	Firm R&D	0.09	0.21	0.43	0.4	0.93	1			
14	Firm resources (cash)	0.07	0.21	0.38	0.37	0.92	0.89	1		
15	Firm leverage (long term debt)	0	0.13	0.33	0.32	0.8	0.7	0.68	1	
16	Firm Capital exp.	0.05	0.19	0.43	0.4	0.95	0.9	0.85	0.78	1

Table 20 shows the results for the Cox proportional hazard model regressions to test Hypotheses 1, 2 and 3. Model 1 is a controls-only model and the variables of interest are added sequentially in Models 2-4. The results are shown in failure time format where a negative (positive) coefficient implies a decrease (increase) in the hazard.

Hypothesis 1 posited that higher technological linkages to the sponsor firms will increase the likelihood of membership in the sponsor-backed standards organization. The coefficient for the measure *Technological linkages to USB standard sponsors* is positive and highly significant in both Models 3 and 4 ($p < 0.01$) supporting this hypothesis. A one standard deviation increase in this variable increases the likelihood of membership in the USB standard by about 27%.

Hypothesis 2 posited that higher relational linkages to the sponsor firms will increase the likelihood of membership in the sponsor-backed standards organization. The coefficient for the measure *Relational linkages to USB standard sponsors* is not significant in any of the models - 2, 3 or 4. Thus, I do not find any support for this hypothesis.

TABLE 20: Essay Three. Results for Hypotheses 1-3. Cox Proportional Hazard Models.

Dependent variable is membership in the USB standard.

MODELS VARIABLES	(1)	(2)	(3)	(4)
Relational linkages to USB standard sponsors		-0.1426	-0.2134	-0.2506
		(0.5933)	(0.6153)	(0.5138)
Tech. linkages to USB standard sponsors			2.9050***	2.5951***
			(0.7921)	(0.9350)
Tech.network position in voluntary standard				2.1174**
				(0.8951)
CONTROLS				
Tech. proposals contribution in voluntary standard	0.2010**	0.2075**	0.1876**	0.1655**
	(0.0879)	(0.0879)	(0.0885)	(0.0806)
Opposition within voluntary standard	0.0302	0.0280	0.0181	-0.0241
	(0.0872)	(0.0858)	(0.0884)	(0.0904)
Patents applied for on voluntary standard	-0.0929	-0.0899	-0.1171*	-0.1570**
	(0.0653)	(0.0608)	(0.0652)	(0.0708)
Patent stock	-0.0001	-0.0000	0.0000	-0.0000
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Citations to patent stock	0.0001**	0.0001**	0.0001**	0.0001
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Firm size (assets)	0.3279	0.3403	0.5137	0.6471*
	(0.3458)	(0.3399)	(0.3272)	(0.3313)
Firm R&D	0.2584	0.2633	0.1421	-0.0526
	(0.3593)	(0.3573)	(0.3563)	(0.3573)
Firm resources (cash)	0.0495	0.0467	0.0375	0.0138
	(0.1565)	(0.1568)	(0.1540)	(0.1589)
Firm leverage (long term debt)	-0.0050	-0.0077	0.0091	-0.0406
	(0.0621)	(0.0639)	(0.0648)	(0.0595)
Firm Capital exp.	-0.3359	-0.3455*	-0.4019*	-0.3860**
	(0.2121)	(0.2087)	(0.2151)	(0.1962)
Observations	1546	1546	1546	1546
Firms	173	173	173	173
Log likelihood	-163.8	-163.8	-160.2	-156.6

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Hypothesis 3 posited that higher technological knowledge network centrality in the voluntary standards committee will be associated with a lower likelihood of membership in the sponsor-backed standards organization. The expected sign for the coefficient of the measure *Technological network position in the voluntary standard* is therefore negative. However, from Model 4 results, it appears that the coefficient for this measure is *positive* and significant, thus giving us results that are opposite to what was predicted. A one standard deviation from the mean for this measure actually *increases* the likelihood that a firm will become a member in the USB standard by about 19%.

Table 21 and Table 22 show the results of the Poisson regressions used to test Hypotheses 4 and 5. Table 21 shows the results of random-effects models and Table 22 shows the results of firm fixed-effects models. Model 5 is a controls-only model and in Models 6 and 7 I sequentially add the hypothesized variables. Similarly, for the fixed-effects estimations, Model 8 is the controls-only model and in Models 9 and 10 I sequentially add the hypothesized variables. Hypothesis 4 posited that higher relational linkages to the sponsor firms will be associated with a higher rate of products supporting the sponsor-backed standard. The coefficient for the measure *Relational linkages to USB standard sponsors* is positive and highly significant ($p < 0.01$) in both Models 6 and 7 in the random-effects case and also in both Models 9 and 10 in the fixed-effects case, thus demonstrating strong support for this hypothesis. There is very little change in the size of this coefficient or its statistical significance across all these models. A one standard deviation increase from the mean for this variable results in an increase of about 6% in the rate of yearly standard-compliant product introductions.

TABLE 21: Essay Three. Results for Hypotheses 4 & 5. Random-effects Panel data Poisson models. Dependent variable is number of products introduced on USB standard.

MODELS VARIABLES	(5)	(6)	(7)
Relational linkages to USB standard sponsors		0.2868***	0.2819***
		(0.0651)	(0.0650)
Tech.network position in voluntary standard			-0.9243***
			(0.1466)
CONTROLS			
Tech. proposals contribution in voluntary standard	-0.2592***	-0.2698***	-0.2571***
	(0.0603)	(0.0610)	(0.0604)
Opposition within voluntary standard	0.0323	0.0283	0.0412
	(0.0396)	(0.0397)	(0.0391)
Patents applied for on voluntary standard	-0.1174***	-0.1227***	-0.1130***
	(0.0153)	(0.0155)	(0.0156)
Patent stock	-0.0003***	-0.0003***	-0.0002***
	(0.0001)	(0.0001)	(0.0001)
Citations to patent stock	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)
Firm size (assets)	0.2978*	0.3315**	0.1180
	(0.1537)	(0.1545)	(0.1582)
Firm R&D	-0.1189	-0.1581	0.0959
	(0.1200)	(0.1202)	(0.1275)
Firm resources (cash)	0.5870***	0.5914***	0.5434***
	(0.0608)	(0.0612)	(0.0621)
Firm leverage (long term debt)	-0.0848***	-0.0823***	-0.0655***
	(0.0231)	(0.0232)	(0.0233)
Firm Capital exp.	-0.0651	-0.0665	-0.0149
	(0.0812)	(0.0816)	(0.0820)
Constant	-29.8686	-29.7912	-29.1001
	(73353.55)	(67759.75)	(56583.6)
Sector (industry) effects	Yes	Yes	Yes
Observations	1412	1412	1412
Firms	175	175	175
Log likelihood	-1355	-1345	-1325
Chi-square	2217	2145	2169

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

TABLE 22: Essay Three. Results for Hypotheses 4 & 5. Fixed-effects Panel data Poisson models.

Dependent variable is yearly number of products on USB standard.

MODELS	(8)	(9)	(10)
VARIABLES			
Relational linkages to USB standard sponsors		0.2840***	0.2794***
		(0.0651)	(0.0651)
Tech.network position in voluntary standard			-0.9453***
			(0.1474)
CONTROLS			
Tech. proposals contribution in voluntary standard	-0.2618***	-0.2722***	-0.2604***
	(0.0605)	(0.0611)	(0.0605)
Opposition within voluntary standard	0.0331	0.0290	0.0416
	(0.0397)	(0.0398)	(0.0392)
Patents applied for on voluntary standard	-0.1185***	-0.1238***	-0.1138***
	(0.0154)	(0.0156)	(0.0157)
Patent stock	-0.0003***	-0.0003***	-0.0002***
	(0.0001)	(0.0001)	(0.0001)
Citations to patent stock	0.0000***	0.0000***	0.0000***
	(0.0000)	(0.0000)	(0.0000)
Firm size (assets)	0.2864*	0.3210**	0.1039
	(0.1552)	(0.1561)	(0.1597)
Firm R&D	-0.1276	-0.1667	0.0939
	(0.1209)	(0.1211)	(0.1285)
Firm resources (cash)	0.5847***	0.5888***	0.5392***
	(0.0609)	(0.0613)	(0.0622)
Firm leverage (long term debt)	-0.0851***	-0.0826***	-0.0651***
	(0.0231)	(0.0232)	(0.0233)
Firm Capital exp.	-0.0662	-0.0679	-0.0156
	(0.0815)	(0.0820)	(0.0823)
Sector (industry) effects	Yes	Yes	Yes
Firm fixed-effects	Yes	Yes	Yes
Observations	337	337	337
Firms	34	34	34
Log likelihood	-1118	-1109	-1088
Chi-square	493.8	499.0	525.6

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Hypothesis 5 posited that higher technological knowledge network centrality in the voluntary standards committee will be associated with a lower rate of products supporting the sponsor-backed standard. The coefficient for the measure *Technological network position in voluntary standard* is negative and highly significant ($p < 0.01$) in Model 7 in the random-effects case and in model 10 in the fixed-effects case, providing strong support for this hypothesis. A one standard deviation increase in this measure from its mean decreases the rate of standard compliant product introductions by more than 12%. It is also worth noting that *Technical proposals contributed on the voluntary standard* is significant and negative in these regressions suggesting that firms that are more and involved in the competing standard are less likely to support the sponsor-backed standard.

Table 23 and Table 24 show the results of the Poisson regressions used to test Hypotheses 6 and 7. Table 23 shows the results of random-effects models and Table 24 shows the results of firm fixed-effects models. Model 11 is a controls-only model and in Models 12 and 13, I sequentially add the hypothesized variables. Similarly, for the fixed-effects estimations, Model 14 is the controls-only model and in Models 15 and 16, I sequentially add the hypothesized variables. Hypothesis 6 posited that higher technological linkages with the sponsor firms will be associated with a lower rate of patenting on the sponsor-backed standard. The coefficient for the measure *Tech. linkages to USB standard sponsors* is negative and highly significant ($p < 0.01$) in all models.

TABLE 23: Essay Three. Results for Hypotheses 6 & 7. Random-effects Panel data Poisson models.

Dependent variable is yearly number of patent claims on USB standard.

MODELS	(11)	(12)	(13)
VARIABLES			
Tech. linkages to USB standard sponsors		-0.5402***	-0.5693***
		(0.2083)	(0.2082)
Tech.network position in voluntary standard			0.6258***
			(0.1131)
CONTROLS			
Tech. proposals contribution in voluntary standard	-0.0412	-0.0417	-0.0475
	(0.0292)	(0.0292)	(0.0292)
Opposition within voluntary standard	0.0426*	0.0492**	0.0430*
	(0.0232)	(0.0232)	(0.0233)
Patents applied for on voluntary standard	-0.0008	-0.0014	-0.0071
	(0.0070)	(0.0070)	(0.0070)
Patent stock	-0.0001*	-0.0001*	-0.0001**
	(0.0000)	(0.0000)	(0.0000)
Citations to patent stock	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)
Firm size (assets)	0.3143***	0.3148***	0.3222***
	(0.1124)	(0.1126)	(0.1128)
Firm R&D	0.2996***	0.2821***	0.2379**
	(0.1049)	(0.1053)	(0.1062)
Firm resources (cash)	0.0978***	0.0946***	0.0756**
	(0.0357)	(0.0359)	(0.0365)
Firm leverage (long term debt)	-0.0855***	-0.0842***	-0.0858***
	(0.0183)	(0.0182)	(0.0182)
Firm Capital exp.	-0.1156**	-0.1041*	-0.0728
	(0.0564)	(0.0565)	(0.0567)
Constant	-5.3884***	-5.2696***	-5.3546***
	(1.5071)	(1.5227)	(1.5088)
Sector (industry) effects	Yes	Yes	Yes
Observations	1330	1330	1330
Firms	172	172	172
Log likelihood	-1774	-1771	-1755
Chi-square	652.1	658.7	682.9

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

TABLE 24: Essay Three. Results for Hypotheses 6 & 7. Fixed-effects Panel data Poisson models.

Dependent variable is yearly number of patent claims on USB standard.

VARIABLES	MODELS (14)	(15)	(16)
Tech. linkages to USB standard sponsors		-0.6764***	-0.7009***
		(0.2140)	(0.2138)
Tech. network position in voluntary standard			0.5986***
			(0.1136)
CONTROLS			
Tech. proposals contribution in voluntary standard	-0.0417	-0.0424	-0.0473
	(0.0292)	(0.0292)	(0.0292)
Opposition within voluntary standard	0.0442*	0.0524**	0.0466**
	(0.0236)	(0.0236)	(0.0237)
Patents applied for on voluntary standard	-0.0010	-0.0019	-0.0073
	(0.0070)	(0.0070)	(0.0071)
Patent stock	-0.0001**	-0.0001*	-0.0001**
	(0.0000)	(0.0000)	(0.0000)
Citations to patent stock	0.0001***	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)
Firm size (assets)	0.3056***	0.3116***	0.3138***
	(0.1181)	(0.1182)	(0.1186)
Firm R&D	0.3116***	0.2811**	0.2414**
	(0.1117)	(0.1122)	(0.1133)
Firm resources (cash)	0.0964***	0.0920**	0.0733**
	(0.0359)	(0.0360)	(0.0366)
Firm leverage (long term debt)	-0.0892***	-0.0873***	-0.0885***
	(0.0188)	(0.0188)	(0.0188)
Firm Capital exp.	-0.1296**	-0.1157**	-0.0819
	(0.0589)	(0.0589)	(0.0592)
Sector (industry) effects	Yes	Yes	Yes
Firm fixed-effects	Yes	Yes	Yes
Observations	921	921	921
Firms	97	97	97
Log likelihood	-1344	-1339	-1325
Chi-square	523.7	537.1	558.7

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

There is little change in the size or significance of the coefficient across models. Thus, there is strong and consistent support for Hypothesis 6 across these models. A one standard deviation increase of this measure from its mean is associated with approximately a 5% decrease in patent claims on the USB standard.

Finally, Hypothesis 7 posited that higher technological knowledge network centrality in the voluntary standards committee will be associated with a higher rate of patenting on the sponsor-backed standard. The coefficient for the measure *Technological network centrality in the voluntary standard* is positive and highly significant in Model 13 in the random-effects case and in Model 16 in the fixed-effects case. Again, there is little change in the size or significance of the coefficient across models. Thus, there is strong and consistent support for Hypothesis 7 across these models. A one standard deviation increase of this measure from its mean is associated with approximately a 8% increase in patent claims on the USB standard.

Graphical view of the results

Figures 6, 7 and 8 below show the plots for the results from the hypotheses tests. Figure 6 plots the independent variables for Hypothesis 1 (*Tech Linkages to sponsors*) and 3 (*Tech network centrality in INCITS standard*) against the hazard of membership in the USB standard. Figure 7 plots the independent variables for Hypothesis 4 (*Relational linkages to sponsors*) and 5 (*Tech network centrality in INCITS standard*) against the yearly rate of product introductions on the USB standard. Figure 8 plots the independent variables for Hypothesis 6 (*Tech. linkages to sponsors*) and 7 (*Tech. network centrality in INCITS standard*) against the yearly rate of patent claims based on the USB standard.

Figure 6: Graphical representation of results from Hypothesis 1 and 3 (Essay Three)

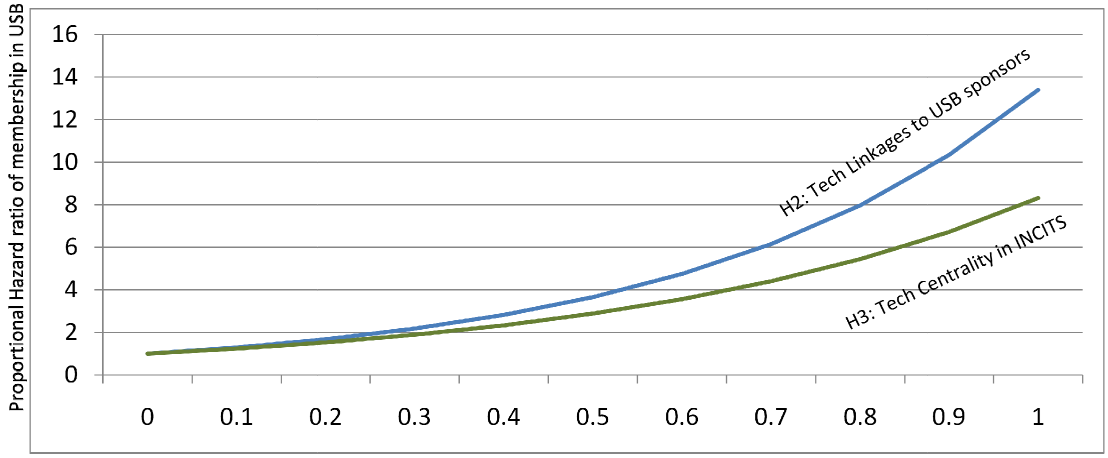


Figure 7: Graphical representation of results from Hypothesis 4 and 5 (Essay Three)

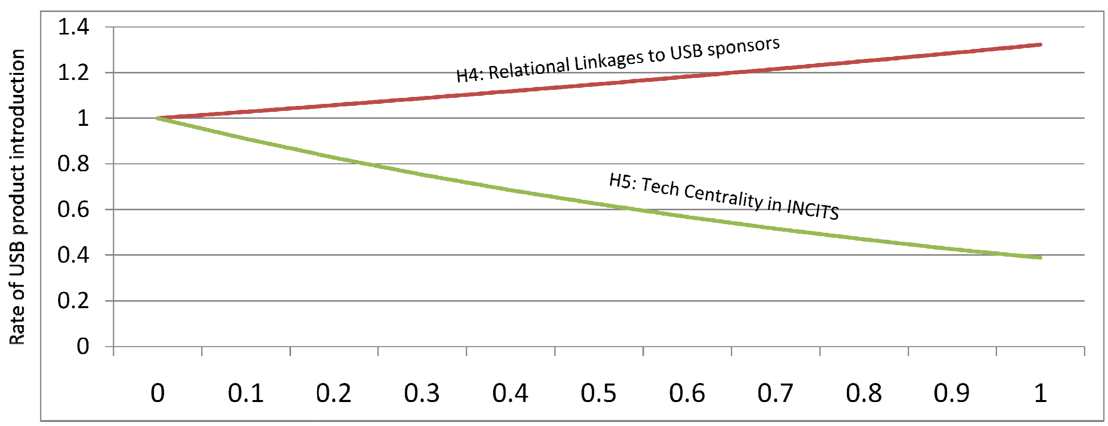
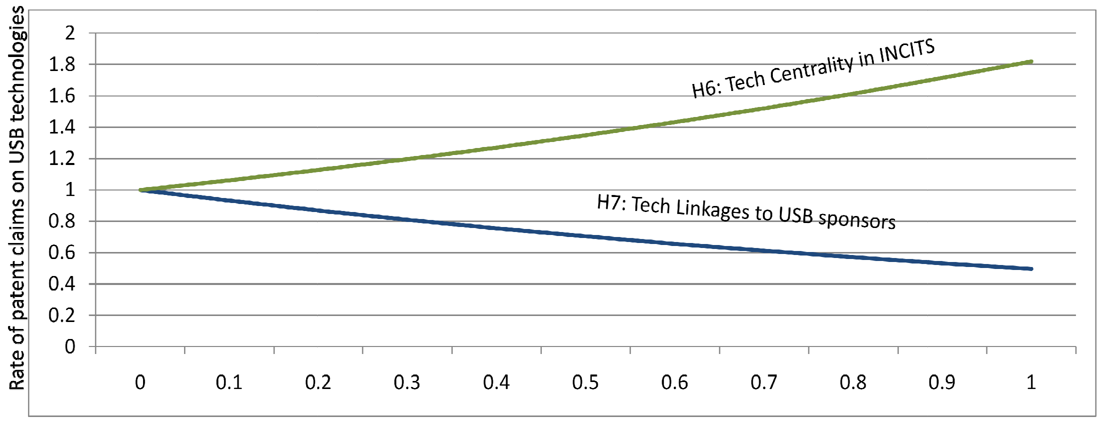


Figure 8: Graphical representation of results from Hypothesis 6 and 7 (Essay Three)



Robustness and alternative explanations

As with most research in strategy, one possible concern is endogeneity - that the results are driven by unobserved factors that correlate with the predictors and the dependent variables observed. However, to the extent that most of these unobserved factors are time-invariant, the strong results in the fixed-effects models, in spite of a small sample in some of the regressions (see Table 22 for instance), alleviate these concerns. As network scholars have suggested, one way to alleviate concerns around the endogeneity of network measures is to use time-varying data that allow the use of lag structures and the incorporation of fixed-effects in the regression models (Stuart and Sorenson, 2007) - this paper takes that approach. Further, I provide the results using random-effects models as well because a large proportion of the firms in the sample drop out in the fixed-effects models if there is either no variation in the dependent variable or there is only 1 year of participation data available. Results across both these sets of models are consistent showing that using both within-firm and cross-sectional variation finds support for the hypothesized arguments.

Additionally, I also control for a variety of observed firm-specific and standards-specific time-varying factors that have been hypothesized in prior research on coalition formation and firms' actions in multi-firm alliances (e.g. Axelrod et al, 1995). The above results are also robust to changes in measures (e.g. using a count rather than a proportion for the independent variables) and assumptions of lag structure. I also tested the models without including the financial controls to test for the inclusion of smaller private firms (these are excluded automatically when financial measures are included in the regressions) and the results were in fact stronger.

Finally, I also separated the alliance data into technology licensing and technology development alliances and ran the regression models for Hypotheses 4 and 5 by calculating the *Relational linkages to USB standard sponsors* measure first for the licensing alliances only and then for the development alliances. The results are much stronger when only the technology development alliances are included and they are weak when only the licensing alliances are included. This suggests that the mechanism underlying Hypotheses 4 and 5 is driven more by the knowledge access and inter-firm routine considerations (capability drivers) that are likely to be stronger in the technology development alliances relative to the licensing alliances.

Discussion

In this paper, I study how firms might navigate competing multi-firm technological alliances. I use longitudinal data from two technologically overlapping standards bodies in the computer industry. My results support the hypotheses that a firm's inter-organizational ties in *both* these rival alliances are crucial determinants of its strategic choices within an alliance. Specifically, I find that the more technologically central a firm is within a network of peer firms in a competing standards body, the less it is likely to support the adoption of an alternate technological standard. This tendency is revealed by two different strategic decisions by firms in these positions - to introduce *fewer* standard compliant products but, at the same time, also make *more* intellectual property claims on the standard they favor less. I also find that the opposite behavior holds to the extent a firm is linked with a standard's sponsor firms - firms introduce *more* standard compliant products but make *fewer* intellectual property claims when they are "closer" relationally (products) and technologically (patents) to these sponsors. These findings are important because they provide large scale empirical evidence that firms' actions in a multi-organizational alliance may be strategically driven by its inter-organizational ties both within the alliance and its inter-organizational position in competing alliances.

Finally, in addition to product introduction and patenting decisions, I also explored how these linkages affect the likelihood of membership. I find only partial support that linkages to sponsor firms increases the likelihood that a firm might join an alliance backed by these firms. I also find an effect opposite to what I hypothesize with regard to a firm's position in a competing standards body. Contrary to my prediction, firms that are technologically central in a competing standard have a higher likelihood of joining the sponsor backed standards alliance. It may be that in dynamic environments, a firm needs to balance the competitive pressure of slowing the competing standard with the pressures of incorporating the technology from that standard if it succeeds, and that in this particular empirical setting, the latter may be a more important influence on the firm's decision.

This paper has several important additional implications for research and practice. Taken together, the findings on firms' product and patenting decisions, suggest that firms may view these as strategically different levers in environments of technological change. Firms that introduce new products on the sponsor's technological standard to bolster the standard's success and strengthen their relational position in the sponsor's network, may also make *fewer* patent claims on that standard for the same reason. In other words, the same underlying mechanism may drive both these decisions but in opposite ways. Although the firms that have capabilities to develop new products presumably also have capabilities to patent the technologies underlying those products, it appears that in the context of a sponsor-backed technological standard, they choose to invest in the former while eschewing the latter. It is important to note that prior research has tended to use *both* new products (e.g. Katila and Ahuja, 2002; Lavie, Lechner and Singh, 2007) *and* patents (e.g. Ahuja, 2000; Joshi and Nerkar, 2011) as measures of technological innovation and performance, and the theories that predict innovation behavior do not clearly distinguish between the two (or implicitly treat both as equivalent measures). This paper provides a critical insight into when the same firm characteristics might predict these two outcomes in opposite ways.

Further, this paper's findings contrast with prior research that has found involvement in multiple standards alliances to increase contributions within a particular alliance (Lavie, Lechner and Singh, 2007; Leiponen, 2008). The reason for the different finding may be that beyond measuring involvement as just membership in the competing standards body (as in Lavie, Lechner and Singh, 2007), I decompose it into four different variables - a network position variable, a patent variable, an opposition variable and a technological contributions variable. The resulting model provides a much more granular measure of involvement that reflects both the level of commitment a firm has made to a competing alliance as well as the benefits that it stands to gain from that alliance.

For firms that need to continuously manage the challenges of technological change, this paper provides several important insights. Even considering the costs of joining multiple standards bodies, it may still be a valuable strategy to be part of these overlapping alliances (Lavie, Lechner and Singh, 2007). For a firm that stands to benefit from an existing standards body, joining a competing alliance early may allow it gain the necessary knowledge to claim intellectual property rights on that standard. This may be a valuable negotiating chip in future discussions with the sponsors. As Ziedonis (2004) notes, if technologies are held by a more disparate set of firms, then the strategic value of patenting for use in licensing transactions is higher. As recent events in several high-technology industries such as wireless telecommunications, software development and computers indicate, patenting is fast becoming a preferred defensive strategy for firms.

From a sponsor firm's standpoint, the finding of opposing effects for product introduction and patenting actions of member firms from an alternate standard is remarkably powerful and informative. Although it is important for the sponsor firms to maintain the balance between protecting their intellectual property (by keeping it secret or heavily patented) and orchestrating a standard (by revealing the technology to spur the development of complementary products), these findings indicate that some member firms that join the standard may act in strategic ways that are not aligned with the sponsor firms' objectives.

These findings are also important for firms that need to understand the conditions under which open standards are likely to lead to widespread adoption (West, 2003). In this particular case, because the existing INCITS standards body was open and consensus-based, firms were able to seek simultaneous memberships in both the INCITS and the USB alliances. Had the existing standards body been closed and sponsor-backed, then conflicts between the two alliances may have been more pervasive to the extent that overlapping memberships may have been prevented. From a sponsor firm's standpoint, while overlapping memberships aid in building up the roster, it might be a wise strategy to limit participation in the standards body, at least initially, to technologically and relationally close firms that do not have conflicting interests. In other words, between making the technology "open-source" at one extreme versus keeping it proprietary and closed at the other extreme, hybrid technology development arrangements that allow for some kind of a phased development of the sponsor's standard may be a more valuable option (West, 2003).

Contributions and Limitations

This paper makes several contributions to research at the intersection of organization theory, strategy and technological change. Prior research on strategic alliances has devoted a lot of attention to firms might enter into collaborations and what the benefits of such collaborations may be. However, most of these studies are at the dyadic level (e.g. Gulati, 1995b, Stuart, 2000; Chung, Singh and Lee,2000) and we know little about why firms might join multi-firm alliances and what the antecedents of their strategic actions in these alliances might be. The few studies on multi-firm network and alliance orchestration have been predominantly theoretical (Das and Teng, 2002; Dhanaraj and Parkhe, 2006; Axelrod et al, 1995), with empirical work being predominantly case-based (e.g. Funk and Methe, 2001; Gomes-Casseres, 1996; Axelrod et al, 1995), with Lavie et al (2007) being a notable exception. In dynamic high-technology environments, the proliferation of overlapping and competing multi-firm standards alliances has resulted in a critical gap between managerial practice and research - the example of Intel's numerous multi-firm technological standards initiatives in an earlier section of the paper clearly underscores the importance of not just focusing the research spotlight on these kinds of organizational arrangements, but also understanding their competitive aspects.

This paper also departs from prior research that has typically used a community or network lens to study the evolution of standards and technological designs (e.g. Wade, 1995; Tushman and Rosenkopf, 1992; Rosenkopf and Tushman, 1998), by exploring firm-level strategic choices to contribute within these communities. Further, while prior studies on network and technological evolution limit their focus to *memberships* in communities or alliance networks (e.g. Axelrod et al, 1995), I distinguish membership from the *contributions* of participating firms in the alliance. Although membership may be an important precursor to the success of a multi-firm alliance, the products and technologies that member firms introduce are more direct measures of the successful evolution of the standard in a technological change setting with network externalities and multiple competing standards. By decoupling these strategic decisions, the essay provides insights into which firms may seek membership in the sponsor-backed standard, yet in principle oppose its adoption. In doing so, it makes an important contribution to firm strategy in a technological change context, by identifying tradeoffs that firms face in making commitments to competing alliance relationships. Finally, this paper contributes to the literature on network evolution by explicating mechanisms that enable or constrain orchestration efforts by sponsor firms (Doz, Olk and Ring, 2001; Dhanaraj & Parkhe, 1996).

The above contributions must be seen in light of the limitations of the study. Although the study does offer robust evidence from a sample of more than 150 firms, it is important to note that it does not study firms' actions beyond the two standards bodies discussed. While INCITS and USB were certainly the dominant peripheral interface standards organizations during the period of study, there were other standards in related technologies such as semiconductors, communications and consumer electronics. Clearly firms may be strategizing across a range of these related technologies (as the Intel example illustrates) but the scope of this study and hence its findings must be viewed with a narrower lens.

CHAPTER 6: CONCLUSIONS

Overview of dissertation findings

The objective of this dissertation was to shed light on firm behavior within and between technology standards-setting committees, with a view to understanding the broader dynamics of multi-organizational arrangements in technological change contexts. I used an inter-organizational conceptual lens to study five distinct actions of firms within two leading standards-setting bodies in the computer industry: (i) voting on the standards committee (Essay One), (ii) forming bi-lateral relationships with other member firms (Essay Two), (iii) joining a competing standards organization (Essay Three), (iv) introducing standard-compliant products on the competing standard (Essay Three), and, (v) making intellectual property claims on the competing standard (Essay Three). Taken together, the findings from these essays, summarized in Table 25, provide robust evidence using longitudinal data from the large number of firms that participated in the leading standards bodies in the computer industry, that existing inter-organizational ties greatly influence firm strategy in multi-organizational settings. Additionally, reflecting the reality that firms are connected to each other in different ways, the importance of considering multiplicity in these relationships is highlighted in the conceptual framework of the dissertation. These findings offer several important insights for both research as well as managerial practice, on the challenges and opportunities of competing while attempting to coordinate a shared direction for technological change.

In Essay One (Chapter 3), I show how firms' positions in technological (patent-based) and relational (alliance-based) networks affect progress towards the coordinated standard. I study the influence of two relationships – technological linkages and strategic alliance ties – on the voting behavior of firms in an information technology standards committee. I find that centrally positioned firms in the technological network exhibit lower opposition to the standard as their knowledge is foundational in developing the standard. In contrast, I find that central firms in the alliance network are more likely to contest the standard - such firms already possess advantageous complementary capabilities that they can continue to exploit without agreeing to the change imminent in a standard. Thus, the influence of network resources on coordination is contingent upon the type of inter-organizational tie. Furthermore, when these relationships are considered jointly, technological centrality moderates the opposing effect of alliance centrality – when firms are in central positions in both networks, they stand to benefit more from the emergence of a technical standard, and thus exhibit greater support for coordination.

In Essay Two (Chapter 4), I examine how divergence in member firms' interests may drive new inter-organizational relationships. I find that although firms that are peripheral in the technological network may be disadvantaged with regard to knowledge relevance in the standard-setting process, they can obtain relational benefits from technologically central firms. To enhance the standard's legitimacy by soliciting wide-ranging participation from firms, central firms may be motivated to forge such alliances.

In Essay Three (Chapter 5), I explore how firms navigate two competing standards - a voluntary standards committee and a sponsor-backed consortium. I examine and contrast firms' product introduction and patenting decisions on the sponsor-backed standard, arguing that while products accelerate the standard's adoption, patents hinder it. I find that while firms that possess prior technological and relational linkages with the sponsor firms tend to introduce more products but fewer patents, the opposite is observed for firms that are technologically central in the competing voluntary standards committee.

TABLE 25: Essays One, Two and Three. Summary of hypotheses and empirical results

E #	**H #**	**Dependent variable**	**Independent variable**	**Proposed relationship**	**Result**
1	1	Votes against standard	Technological network centrality	Negative	Supported
1	2	Votes against standard	Alliance network centrality	Positive	Supported
1	3	Votes against standard	Technological network centrality & Alliance network centrality	Negative	Supported
2	1	Likelihood of alliance	Technological network centrality	Positive	Supported
2	2	Likelihood of alliance	Involvement	Positive	Supported
2	3	Number of alliances	Asymmetries in technological network centrality & involvement	Positive	Supported
3	1	Membership	Technological linkages to sponsor firms	Positive	Supported
3	2	Membership	Relational linkages to sponsor firms	Positive	Not supported
3	3	Membership	Technological network position on voluntary stand.	Negative	Not supported
3	4	Count of products	Relational linkages to sponsor firms	Positive	Supported
3	5	Count of products	Technological network position on voluntary stand.	Negative	Supported
3	6	Count of patents	Technological linkages to sponsor firms	Negative	Supported
3	7	Count of patents	Technological network position on voluntary stand.	Positive	Supported

Scope and limitations

The theory and the findings of this dissertation need to be bounded by six important considerations - three conceptual and three empirical.

First, conceptually, this dissertation makes an assumption that relevant technological knowledge for setting the standard is both distributed between several firms and interwoven amongst them. This is a tenable assumption only in industries such as the focal empirical setting, where technological innovation is decentralized (Bresnahan and Greenstein, 1999). In such industries, products are modular (Schilling, 2000; Baldwin and Clark, 2000), innovation in the different underlying subsystems progresses at different rates, and network externalities influence technology adoption (Katz and Shapiro, 1986). These assumptions may not hold in process-based industries (e.g. oil & natural gas, cement manufacturing) where production activity is sequential and tightly coupled and network externalities are limited or non-existent. However, the properties of most industries that undergo continuous technological change tend to be similar to those of the industry selected for study in this dissertation. Certainly the implications and findings of the dissertation should be limited to technological change contexts.

Second, this dissertation makes an assumption that the critical complementary capabilities to profit from innovations are generally extra-mural (Teece, 1986; Lee, Lee and Pennings, 2001). This is also a tenable assumption to make in vertically disaggregated industries - in vertically integrated industries such an assumption may be inappropriate.

Third, although my level of analysis is the firm or the dyad, involvement and interaction in standards-setting committees really occurs at the individual person (engineer) level. In aggregating individual behavior up to the firm, the important underlying assumption is that firms' representatives act to reflect their corresponding firms' interests. While this may be true in a majority of multi-organizational settings, it is important to note that there may be instances where individual participation is independent of private organizational interests.

Empirically, my arguments assume that decision-making is consensus-based, that there are no barriers to membership and that all participating firms have equal rights on the standard-setting committees. Thus, these arguments are valid only to those types of multi-firm organizations with these characteristics. The second empirical assumption is to do with the structure of the underlying inter-organizational networks of participating firms. I assume that a distribution of firms' positions in the networks of interest exists and that the networks are generally connected. In other words, if there is a single hub firm and all ties originate from such a hub firm, then there will be no variation in the network data. Similarly, if the network consists of nodes that are largely disconnected from most other nodes (e.g. cotton, paper and leather in Rosenkopf and Schilling (2007)), then centrality may not be a good predictor of firm behavior. Finally, the arguments, especially in Essay One, also make an empirical assumption that the two inter-organizational networks (technological knowledge and strategic alliances) are not perfectly correlated. While there may certainly be some common drivers of path-dependence between inter-firm technological innovation and the formation of strategic business linkages (e.g. Stuart, 2000), it is reasonable to assume that they are not completely concomitant. For instance, the factors driving the formation of vertical alliances for contract-based manufacturing (e.g. cost) are likely to be different from the factors driving which firm's technological knowledge to build on (e.g. innovativeness or novelty).

Contributions

The highlights of the dissertation are summarized in Table 26 below.

TABLE 26: Dissertation Highlights

	Essay One	**Essay Two**	**Essay Three**
Strategic action	Contesting the emerging standard	Forming a bi-lateral relationship	Membership, products and patents in another standard
Underlying tension	Allowing tech. change versus exploiting existing position	Building legitimacy for the standard versus pushing it through	Helping the standard diffuse versus slowing its adoption
Theoretical mechanism	Contesting effect of centrality in alliance network moderated by supporting effect of centrality in the knowledge network	Asymmetry in involvement and technological positions influences collaborations between central and peripheral players	Links to sponsors increases products but reduces patent claims. Position in competing standard results in opposite effects.
Empirical approach	Panel data Poisson models	Panel data logistic regression models and panel data Poisson models	Cox proportional hazard models and panel data Poisson models

First and foremost, the findings and implications of this dissertation strongly advocate a shift from studying and measuring capabilities at the firm level to focusing on inter-firm capabilities that may exist within strategic inter-organizational networks, in particular for scholars and practitioners interested in studying firm behavior in multi-organizational settings. In all the three essays, significant effects were found for different inter-firm measures *after* statistically controlling for firm-level capabilities.

While the relational view of the firm (e.g. Dyer and Singh, 1998) has long emphasized that the relationship between firms is an important unit of analysis, this dissertation advances this view by examining the nuances of different such relationships. In an increasingly interconnected corporate landscape, firms are linked together in different ways and at different levels, but we know little about the tradeoffs and the tensions underlying these multiplex connections. By establishing a relationship between firms' positions in two important and salient such inter-organizational networks - technological and alliance - this dissertation emphasizes the simultaneous consideration of multiple inter-organizational relationships when modeling firms as actors in multi-organizational settings (e.g. Shipilov and Li, 2010).

Beyond simultaneous consideration of these multiplex relationships, this dissertation also reveals hitherto unexplored mechanisms of tie formation within these networks. In particular, by theorizing on how firms may attempt to offset their growing technological marginalization resulting from the emerging standard by forming ties with central firms, Essay Two informs the substantial body of research on alliance formation. Thus in addition to a network formation theory of relational, social and technological capital, there may be "political" capital drivers at play as well. The conflicting needs to enhance legitimacy but at the same time control the standard to be based on a central firm's foundational knowledge, may create the conditions and incentives for such bridging ties to emerge.

The findings from the dissertation also underscore an important point that the effect of an inter-organizational network position on a firm's actions is both context dependent and relation-type dependent. Not only may the same tie may predict firm behavior differently in *different* network contexts, but different types of ties may also predict behavior differently in the *same* network context. Further, there may be competing incentives arising from each type of tie that essentially reflect the uncertainty and complexity of the underlying business context. As Essay One demonstrates, although the rents from firms' external complementary capabilities may be preserved in the existing technological regime by partner scarcity or time-compression diseconomies (Dyer and Singh, 1998), the move to a new technological standard has the potential to erode these rents, and this in turn may create disincentives for firms to support technological change at the network level. Similarly, while centrality in the knowledge network in one standards context supports the emerging standard, the same centrality has an opposite effect in a competing standards context as firms may behave strategically to preserve network rents.

The focus on tie multiplicity also adds to an emerging debate on the divergent foundations and effects of knowledge and power in networks (Reagans and Zuckerman, 2008). While the technological network position can be conceptualized as representing a firm's knowledge position relative to peers, the alliance network position - a resource dependency relation - can be conceptualized as representing a firm's power relative to its peers. In a consensus-driven standards-setting context, where the negotiations are driven by technical considerations, the knowledge network position appears to be more influential than the power network position.

Beyond contributing to the relational view and strategic networks, this dissertation also makes important contributions to what has already been a central direction of inquiry in strategic management and organization theory research - how do firms compete in environments characterized by technological change (e.g. Henderson and Clark, 1990; Anderson and Tushman, 1990)? Recent research that has highlighted the importance of "dynamic capabilities" for firms in such environments (Teece et al, 1997; Helfat et al, 2007; Winter, 2003), has primarily focused on the ability of firms to modify and extend their existing capabilities to adapt to technological change. The ability of firms to systematically control or direct technological change has not received similar attention (cf. Teece, 2007). By creating and availing of opportunities to shape change in technical consortia that adjudicate amongst technological alternatives, firms have the capacity to shape technological outcomes in ways that enhance the value of their unique resources and capabilities (cf. Suarez and Utterback, 1998). This dissertation explores the characteristics of firms that are able to shape such change and the strategic choices they make to control change. It also makes an empirical contribution to the dynamic capabilities literature by showing how network-level capabilities (Rothaermel and Hess, 2007) may help firms control technological change. As summarized in Table 26, all the three essays focus on strategic choices firms make to control change - namely, supporting or opposing a standard (Essay One), attempting to build a broader consensus to support a particular technological direction (Essay Two) and using patents and products to control the technological evolution of standards (Essay Three).

Understanding decision-making in these consortia may also provide additional insights for both managers and policy makers who are interested in determining whether these coordinated outcomes promote industry-wide decisions that benefit consumers or whether they support only a few advantaged firms. Technical consortia are settings which are inherently characterized by conflict as firms with divergent interests seek to forge common ground. Essay One in this dissertation elaborates on the conditions for a network form of governance (Kogut, 2000) to enable the resolution of these conflicts. The findings from this essay with regard to policy questions are mixed - while it appears that firms that are central in the alliance network are not able to wield their power to shape the standard favorably (thereby contesting it), it is also apparent that there is a systematic effect of firms being technologically peripheral in the network and contesting the standard. In other words, consistent with the dominant design theory (Tushman and Anderson,1986), firms elaborating the dominant design tend to coalesce around the knowledge that has been foundational in determining the dominant design and driving the innovations of the community of firms. While this may not necessarily be detrimental from a societal standpoint, it does raise additional questions about the inertia of knowledge, innovation and the potential crowding out of novel ideas from technological standards emerging out of these committees.

From a managerial standpoint, firms not only need to make decisions whether to support standards, but also need to evaluate the investments they need to make in sending engineers to participate in drafting and contributing to these standards. These decisions are becoming more critical given the proliferation of standards forums in technology-driven industries and their strategic importance. Managerial research on such types of arrangements is very emergent (Rysman and Simcoe, 2008; Waguespack and Fleming, 2009) as the research focus in the 1980s on standards was studying the effect of network externalities and standards wars (e.g. Katz and Shapiro, 1986), and not the coordinated technology committees that characterize standards-setting today. A lot of the prior work on de-jure standards-setting is also case-based (e.g. Gawer and Cusumano, 2002; Garud et al, 2002, Funk and Methe, 2001; Fontana, in press) and by providing robust large scale evidence of the effect of inter-organizational relationships, this dissertation enhances our understanding of firms' strategies in these technological change contexts.

Future Research Directions

This dissertation also offers several fruitful avenues for future research in the areas of alliances, networks and technological change.

First, this dissertation is based on a single industry study in a standards-setting context that had two major industry-level standards committees. Future research could attempt to replicate this study in other settings, keeping in mind the scope limitations outlined in the prior section.

Second, although they reflect an accurate track record of firms' actions, all the data used in this study were obtained from archival sources. The findings using this data could be greatly benefited by obtaining richer qualitative insights through participant interviews and/or ethnographies. Similarly, by analyzing data from meeting minutes and email interactions of participants, even more granular measures that better reflect the tensions underlying the standard-setting process, can be constructed. This would help us understand whether the firm representatives in standard-setting committees cognitively view the underlying networks the same way as this dissertation conceptualizes them.

Third, building upon Essay Two, studies could also explore other mechanisms where central players in the standards committee try and build legitimacy and broaden the involvement of peripheral players. The movement of engineers across these organizations (Dokko and Rosenkopf, 2010) and investment of corporate venture capital into peripheral firms (Dushnitsky and Lavie, 2010) may constitute two examples of such alternate mechanisms. Recent research on patent pools (Joshi and Nerkar, 2011) has also revealed another interesting mechanism by which firms can accelerate standards adoption in settings that are marked by a complex web of intellectual property claims.

Fourth, empirically extending the concept of tie multiplicity, studies could consider the independent and joint influence of different types of inter-organizational relationships. For instance, individual-level ties between firms at the engineer level, financing ties or other types of interlocks between firms could be the focus of additional empirical work. It would be especially interesting to analyze contexts where tradeoffs between different types of inter-organizational ties exist.

Fifth, the proliferation of such multi-firm standards organizations also makes it a very interesting and managerially relevant question to study the effect of membership and involvement across a larger set of standards-setting bodies on various dimensions of firm performance such as financial performance, innovative performance and firm survival (e.g. Waguespack and Fleming, 2009; cf. Lazzarini, 2007). Such a study could build on the emerging work and conceptual ideas from the alliance portfolio literature (e.g. Lavie, 2007; Lavie and Miller, 2008).

Sixth, research on standards-setting and technological change could also greatly benefit by an in-depth qualitative focus within a single firm, with a broader objective of understanding the integral role standards-setting plays in overall firm strategy. A firm that is involved in several hundred standards initiatives is likely to have the structure and routines in place to direct participation across these initiatives and at the same time assimilate knowledge from such participation to drive business and corporate strategy.

Finally, this dissertation only looked at entry into and participation within standards organizations. Clearly, exit from these organizations is also an equally important strategic action that deserves research attention. As Lavie, Lechner and Singh (2008) note, the market does not salute companies that fail to abandon a sinking ship. Building on this dissertation, it would be insightful to contrast exit decisions with entry and involvement choices. In particular, building and testing a theory around the asymmetric nature of entry and exit would allow us to gain further insights into the determinants of technological evolution.

Conclusion

To conclude, the primary objective of this dissertation was to open up the "black box" of firm behavior in multi-organizational settings and examine its contents using an inter-organizational lens. While the resulting findings have greatly enhanced our understanding of the dynamics within these organizational communities, they continue to remind us that interactions between firms within such communities and interactions between competing communities are important determinants of technical change. My particular interest in focusing the inquiry of this dissertation on technology standards-setting organizations stemmed from the sheer proliferation of these large-scale arrangements that are coordinated but at the same time embedded within a market-driven economic landscape. While the larger policy debate has been (and should be) whether as a society of technology consumers we benefit from these innovative organizational mechanisms that orchestrate technological evolution, this dissertation calls attention to the role that strategic management and organization theory scholars can play in contributing to this ongoing debate. By applying, synthesizing and extending knowledge on the inter-organizational determinants of technological change that are rooted in the relational view of the firm and strategic network theory, this dissertation has established a clear roadmap for future studies to continue to examine and uncover the richness of this multi-faceted phenomenon.

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